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Statement to the Joint Committee on Washington, DC, Metropolitan Problems

WILLIAM VICKREY

FOREWORD

In 1959, William Vickrey presented a statement, along with exhibits and appendices, to the Joint Committee on Washington Metropolitan Problems. Judging the material to be of considerable historical interest in the context of urban economic transport theory and policy, and to rescue it from obscurity, we recommended to the Editor that it be published in the *Journal of Urban Economics*. The Editor graciously assented, subject to some editing.

The statement provides an overview of Vickrey's thinking on the technological implementation of efficient urban transport policy. The appendix to the statement presents "A Preliminary Sketch of Possible Schemes for Automatic Toll Assessment with Reference to the Washington, DC, Metropolitan Area." Exhibit 51 is an essay, "Reaching an Economic Balance between Mass Transit and Provision for Individual Automobile Traffic." The appendix to that exhibit contains a derivation of Ramsey–Boiteux pricing in the context of urban transportation. Exhibit 52 deals with the "Construction of Tentative Fare Schedules for Washington, DC, Regional Rapid Transit System." Exhibit 53 is an essay on "The Economizing of Curb Parking Space—A Suggestion for a New Approach to Parking Meters."

The total length was some 100 typewritten pages. To transform this material into a journal article, we decided to include the statement, moderately edited, along with the appendix on automatic toll assessment and the exhibit on curb parking space. We hope to find a venue for publication of at least some of the residual material elsewhere.

The article not only demonstrates Vickrey's creativity, economic intelligence, and farsightedness, but also provides further evidence that he is the source of pricing solutions to urban transport problems. With the tremendous advances in technology over the last thirty-five years, his proposals are even more compelling now than they were when originally formulated.

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My purpose in appearing here before you today is to lay before you certain possibilities for promoting the efficient utilization of transportation facilities that have only recently become technologically realizable. Recent technological developments in electronics have placed within reach and within reasonable cost the possibility of assessing against the users of metropolitan streets and highways a set of charges that can be tailored about as closely to the costs occasioned by the actual usage as these costs themselves can be estimated. This can be done without interrupting or even slowing the flow of traffic, and at a cost that will be minute compared to the savings produced in inducing a more economical and less congested pattern of traffic flow and a more economical apportionment of traffic between the various available modes of transportation. It would, moreover, go far toward solving the financial problems associated with the provision of the expensive facilities required to provide adequate transportation in a modern metropolis.

Before trying to present the techniques that might be used, I would like to indicate in a general way why it is particularly important to bring metropolitan highway use under a pricing system such as we use for water, telephone, electricity, or mail service.

It is relatively rare that additional traffic on metropolitan streets and highways can be accommodated in the flow without at least some impairment of the free movement of the previously existing traffic. More important, the cost of providing additional roadways is vastly greater than for rural highways. This is brought out by the fact that even within the Washington metropolitan area, costs per lane-mile for the additional construction contemplated under the "auto-dominant plan," plan I, over and above that provided for in the recommended plan, plan IV, amount to some $3 million for the mileage within the District of Columbia, as compared with only $600,000 per lane-mile in the remainder of the metropolitan area, even though this latter construction still involves some fairly heavily built-up areas. A gasoline tax that might be an appropriate charge for the use of rural highways thus becomes totally inadequate to provide a reasonable approximation to the cost for users of the metropolitan streets and highways.

It is instructive to bring out explicitly just what the magnitude of the appropriate charges would be if the costs of urban traffic are to be brought home to the individual user. The transportation survey that has been carried out under the auspices of the National Capital Planning Commission provides us with excellent data to show how extremely expensive it is to provide for highway service on the scale demanded by the traffic levels projected for 1980. If we compare the "auto-dominant" plan I with the "recommended" plan IV, we find that the difference in capital costs for highway construction is $568 million, while the difference in the cost of parking facilities is another $125 million, a total of $694 million. If we ask what this extra $694 million is providing for, we find that the difference in the number of passenger trips by private automobile is 250,000 per working day. But of these, something over half are non-rush-hour trips that would have been adequately accommodated on the smaller highway system without undue congestion; the trips that actually gave rise to the need for the larger highway system are the rush-hour trips, which can be estimated at roughly 108,000 per day. Using an average of 1.8 passengers per car, and converting to a round-trip basis, this gives 30,000 car round trips per day during the peak traffic periods. Dividing the difference in investment by the difference in car round trips, we find that for each car that makes a daily round trip during the rush hours, an investment of $23,000 must be made to provide the needed roadway and parking space. Or to put the matter in somewhat larger terms, for each 1000 cars added to the daily rush-hour traffic, $23 million, more or less, must be spent on highways and parking facilities to maintain the flow of traffic at the same standards of freedom from congestion.

Assuming that some figure of this general magnitude is valid, it would be very much in order, before embarking on any plan involving expenditures on this scale, to ask just how many people who drive their car to work during the rush hours would be willing to continue to do so if the car they had to use cost them $25,000 instead of $2000? Or, to put it another way, how often would the average driver be willing to pay $4 or so per round trip for this privilege, so as to amortize this $23,000 investment on the basis of 250 working days a year and 4% interest? All this, of course, would be over and above the cost of maintaining and operating the car itself. And if the average driver, or even a substantial number of them, would not be willing to make such a payment, but would rather use a reasonably adequate mass transit facility, is it proper to spend the money in this way for him, make no charge or only an inadequate charge for the use of the facility, and then levy added taxes on him as he and others abandon mass transit and swarm over the "free" facility?

It is no use arguing that in some average sense the average motorist pays for what he uses through higher gasoline taxes or higher license fees, or even through higher property taxes or income taxes. Unless the amount he pays is made to vary specifically with the amount of his own individual rush-hour usage of the highways, the results can be disastrously expensive. The situation is somewhat comparable to what sometimes happens when a group meets at a restaurant and decides, in order to reduce the bookkeeping, that the group bill will be split evenly among the members. Unless the members of the group are unusually unselfish in their behavior, what frequently happens is that everyone finds himself eating a high-priced steak dinner, and of course paying for it, since no individual will be able to reduce his own share of the group bill very much by his own self-restraint, even though most or all of the group would have preferred to economize with the goulash.

As long as no substantial direct charge is made for the use of the highway system, it is very difficult for a mass transit system to fulfill its proper role. Even if mass transit service is free and of excellent quality, it can attract only a limited patronage in competition with the free highway system, particularly in a community with a high and rapidly rising standard of living, unless, indeed, the highway system is kept so limited that it becomes seriously congested while by some means this congestion is prevented from similarly affecting the transit system. And, of course, a poorly patronized transit system is likely to provide relatively infrequent service, which, in turn, results in poor patronage in a vicious spiral.

In terms of recent and current technological developments, there are at least two reasonably feasible methods of assessing charges for the use of the metropolitan streets and highways in close correspondence to the nature and amount of use. The basic principle in both of them is that an automatic record is made of the identity of cars passing a number of checkpoints. These records can be made without any need for the continuous presence of personnel at the checkpoints, and without any need for the cars to slow down. These records are then taken to a central processing center, where the records are transferred automatically to magnetic tape, and are then sorted by a digital computer, which, when it has assembled all of the records pertaining to a particular car, will determine an appropriate charge in accordance with the time and location of these various records, and prepare an itemized monthly bill ready for mailing to the registered owner of the car.

The two methods differ primarily in the method by which this initial record is made. One of these methods is electronic, and the other photographic. While each of these methods has some advantages that the other lacks, the present discussion will deal primarily with the electronic method, since this is at the stage where a working model is available.

Roughly, we may consider that the traffic projections contemplate some 5 million passenger trips per day, or about 3 million car trips per day—90 million car trips per month—so that if a fairly dense network of detection stations is assumed, such as to produce an average of three observations per trip, we have a total of about 300 million observations a month to process. The handling of such data volumes is well within the capabilities of computers that are now available at a quite reasonable cost.

Discussions I have had with Census Bureau officials suggest that the maximum job of processing 300 million observations could be performed using equipment similar to that in operation at the Census Bureau and programming techniques also not greatly different from those currently in use. The central processing equipment can be purchased for roughly $9 million. This is a maximum figure. If to this we add some $4.5 to $8 million for the peripheral detection and recording equipment, and $40 million for some 2 million response blocks at $20 each, the total cost of the system comes to well within $60 million, even for a maximal system.

I would like now to review some of the salient potential advantages of a flexible and specific pricing system such as the one we have just been describing. One of the advantages of this pricing system is its extreme flexibility, which can be used, among other things, to improve the efficiency of the traffic distribution. For example, traffic between points on opposite sides of the central area can often be provided for most economically by an outer or intermediate loop route, which, while it may be slightly longer than a direct route through the center or via an inner loop, involves much lower construction costs. Without pricing either the inner loop is built to a restricted capacity and congestion develops which induces some of the traffic to use the outer loop, or large additional sums must be spent in providing additional lanes for the inner loop, whereas adding the same capacity to the outer loop route would be very much less expensive and might involve in many cases only a negligibly longer driving time. Pricing makes it possible to divert the traffic for which the minute or two saving in time is not worth the difference in cost, from the inner loop route to the outer loop route, thus lowering the total cost of the highway system. Moreover, the pricing system is flexible enough so that at periods of low traffic volume when ample capacity exists in the inner loop, traffic can flow through the inner loop uninhibited by any charge. The diversion is thus limited to the periods during which it is necessary.

More generally, the form of pricing being suggested here would make it possible to impose restraint on the use of highways during periods of threatened congestion without detracting from the fullest economical usage of the highways at other times. This means, among other things, that an appropriate incentive can be automatically provided for those who can avoid the use of the highways during the rush hours, and to transfer their usage to hours when the traffic is lighter. This, in turn will "spread the peak" in a manner more general and less arbitrary than through imposing arbitrary "staggering" of hours, and the costs of the system will be shared over a larger number of peak users per lane of road, which in turn will make it possible to reduce the charges for peak use considerably below the figure of $4 per round trip indicated above.

Pricing of highway use will thus make it possible to provide at reasonable cost uncongested and speedy transportation anytime, anywhere, and for anyone for whom the occasion is sufficiently urgent to warrant the payment of the corresponding charge. Without pricing, it is very likely that during the rush hours this degree of freedom of movement would not be

available to anyone at any price, short of the cost involved in the advance clearing of the route, unless indeed the entire highway system is expanded to extravagant levels.

It is a specific feature of the pricing system suggested here that it is to be applied to the street and highway system as a whole, and not merely to bits and pieces of it. Where tolls are collected only on selected facilities, such as on the bridges, tunnels, and parkways in the New York area, this often has a very unfortunate effect on the routing of traffic. Not only is there a certain amount of "shun piking" around to toll stations on the parkways, but there is a great deal of diversion of traffic away from new capacious facilities on which tolls are charged and toward the older, more congested facilities which have acquired a "free" status. As examples of this we have the Manhattan approaches to the Queensborough and Manhattan Bridges: The imposition of tolls on these bridges and the corresponding reduction of tolls on the competing facilities such as the Triborough Bridge, the Queens Midtown Tunnel, and the Battery Brooklyn Tunnel would go a considerable way toward relieving these seriously congested situations. Such situations would be avoided entirely under the scheme suggested here.

As applied to Washington, it is contemplated that the control points should more or less completely block off the area into zones, so that it would not be possible to go from one zone to another without passing a checkpoint. This does not necessarily mean that the charge should be the same on an expressway as on a local street, but that any difference in charge should be made to correspond to some public interest in inducing the motorist to choose one route rather than another. It would not, in general, be possible for the motorist to obtain a lower charge by using an abnormal route unless that route is in some relevant sense a low-cost route at the time, whether because of reduced construction costs or usage below capacity traffic.

Although the system is conceived primarily as a means of inducing a more efficient usage of the highway system, with due regard on the part of the users to the costs they occasion both to other users and to the highway authorities, the operation of the system will result in very substantial alleviation of the otherwise almost unmanageable financial burden on the jurisdictions involved. If we take as a basis for estimate the traffic projected plan IV, and assume a level of charges intended to reflect the unit costs of augmenting the system to take care of additional traffic, we could expect the usage charges to take care of the carrying costs on some $1420 million of outlays, which at 5% would imply an annual revenue of $71 million per year. The capital costs of the equipment required for the pricing scheme could thus be written off with something to spare from the first year's revenues. As an added benefit there would be preserved at all times a freely flowing and relatively uncongested highway system, a situation that would probably not be maintained under plan IV as it stands without usage charges.

If, however, as seems likely, the usage charges on the scale advocated here should result in a substantial shift in traffic from private automobile to mass transit, it might be found that all of the economically worthwhile vehicular traffic could be taken care of with a much smaller outlay for streets and highways. If, for example, we assume that the proportion of traffic attracted to the express transit system is double that contemplated under plan IV, which I think is a not entirely inconceivable outcome, the peak vehicular traffic to be accommodated would be only some 60% of that indicated under plan IV, the capital cost of the new highway construction would be reduced from some $1803 million to around $1300 million, and the usage charges would cover the carrying charges on some $850 million of this. The heavier utilization of mass transit under this system would make worthwhile a much more convenient and frequent service than would otherwise be feasible or justifiable. Rail rapid transit would become worthwhile for a larger number of routes, and express buses could be operated in the relatively congestion-free traffic without resort to the uneconomical expedient of partially utilized special lanes.

I. A PRELIMINARY SKETCH OF POSSIBLE SCHEMES FOR AUTOMATIC TOLL ASSESSMENT WITH REFERENCE TO THE WASHINGTON, DC, METROPOLITAN AREA[1]

1. *Zones, Segments*

We suppose the metropolitan area to be subdivided into suitable zones of such a size that trips remaining within a single zone will make a negligible contribution to traffic congestion or the magnitude of the highway system needed. These zones will range in size from a mile or possibly less in diameter in the center of the area, becoming larger in the less congested areas; peripheral zones may be laid out so as to be generally longer in the circumferential direction than wide in the radial direction. Zones will be laid out so as to generally minimize the number of thoroughfares crossing zone boundaries. Each thoroughfare that crosses a zone boundary will be equipped with registration apparatus capable of identifying each car as it passes and making a record of the identity of the car and the time of passage. As a rough guess, the identification equipment might be thought of as being set up to cover 5000 lanes of traffic; the number of zones might be between 60 and 200. For purposes of processing, the portion of zone boundary common to any two given contiguous zones would be termed a segment; many segments might cover only 2 or 4 lanes, but some might have as many as 80. There may be from 150 to 500 segments.

[1]All figures given here are intended as merely a rough indication of orders of magnitude, and are merely preliminary impressions rather than estimates.

2. *Methods of Identification*

(*a*) *Link tracer system.* Each vehicle registered in the area would be required to carry in a suitable location an identity block, consisting of static electrical elements embedded in a plastic block. These blocks are estimated to cost $20 or less and need no batteries or other power connections. At zone boundary crossings, interrogator apparatus would probe the lane with electromagnetic waves, and the reaction of the response blocks would provide the information as to the identity of the car. A single interrogator would be able to handle several lanes of traffic over a radius of a quarter of a mile or more. The exact number in a given case would be a matter of relative cost. For each car thus detected, a record would be made giving the identification number of the vehicle, the date, the time, and the number of the route within the segment. (As will be indicated later, the identity of the segment need not be recorded for each vehicle, but only for the series of records as a whole, as this information can more economically be added at a later stage in the processing.) The record may be made conveniently in any way suitable for further processing; for the lightly traveled points, at least, paper tape punching will probably be the more economical method. The identity number recorded may also be displayed if desired, so that a driver can assure himself that the apparatus is working properly.

It will, with this system, be necessary to have some control over possible tampering with the response blocks, or failure to mount them properly as required, as well as to limit abuses in the use of out-of-state license plates (i.e., plates other than District of Columbia, Maryland, or Virginia). Provision should be made for the mounting of automatic cameras, at a selected subset of the checkpoints, arranged to take pictures of all cars for which no response is obtained, together with an indication of the time and of the fact that no response was obtained. These cameras would also be arranged to take pictures of a random sample of those cars that did produce appropriate responses, together with an indication of the electronic response obtained, so that the response can be checked against the license plate number and any discrepancy dealt with appropriately. Such cameras might be mounted permanently at some of the high-density points, and in particular along some complete cordon so as to provide a complete check of the entry and exit of all cars, to and from the center of the metropolitan area, but they should also be moved about at irregular time intervals among the medium and low density points within the area as well. Display of the number recorded would also serve as a check against tampering, since a lack of correspondence between license plate number and number displayed could be observed by inspectors and others.

(*b*) *Taller and Cooper—intelligent machines research system.* Each boundary-crossing lane is equipped with an automatic camera, a treadle, and illumination, so arranged that the passing of the car over the treadle actuates the camera, and if necessary the lights, so as to take a picture of the car and its license plate. The cost of the film and its processing is estimated at about 0.125 cents per frame, i.e., 800 frames per dollar. These films are collected at suitable intervals and brought to a central processing shop where they are developed and then put into a special reading machine which will automatically search for the license plate on the negative, read the license number, and convert this information, together with information as to the time of the observation and the location of the route within the segment, to an item on magnetic tape. The cameras used in this operation would be essentially similar to those now used in connection with toll collection stations on various toll roads such as the New York State Thruway. The reading machine would need to be specifically developed for this purpose; it would be essentially a modification of machines now being used and developed at IMR for the automatic sorting of mail, the reading of account numbers impressed in carbon on the back of gasoline invoices, in accounting for credit card purchases, and the like. It might prove necessary or desirable to modify the style of numbers on the license plate, provide a special form of border to assist in the finding of the license plate on the negative, or possibly to use special paints or coatings to intensify the image, as well as to distinguish local license plates from out-of-state ones, especially on trucks bearing multiple plates. There appears to be no reasonable doubt that given a modification of the license plate pattern, a reading machine could be developed that will give satisfactory results, though unlike the Link apparatus, a working model is not yet available.

Sufficient checking can be built into the system at one point or another so that erroneous identifications would be sufficiently unlikely to cause difficulty. Whenever the automatic machine fails, possibly after repeated attempts to read a particular frame, arrangements can be made to read this frame manually, say by causing a hole to be punched in a corner of the frame, which would cause the film subsequently to be stopped with this frame projected on a screen; a clerk would then read the license plate if it is humanly legible, and punch the license number and State, if required, on a keyboard which would cause the appropriate entry to be made on a tape.

3. *Volume and Nature of Data Generated*

Whether generated from photographs or from electronic scanning, the records generated would be transferred to magnetic tape, and the subsequent processing would be roughly similar. Each original item would consist of the identification number of the vehicle (30–40 binary digits or "bits"); day of the month (5–6 bits), hour of the day (5 bits), minute (6 bits), and second (to the nearest 2 seconds; 5 bits); current traffic density at the point, and possibly at neighboring points (5 bits); direction (1 bit); and location within the segment (5 bits). The whole item should thus fit comfortably into 72 bits, constituting two computer "words" of 36 to 48 bits each. A reel of tape containing 4700 blocks of 720 6-bit lines would thus accommodate 280,000 items.

Traffic projections for 1980 on the assumption of unrestricted use of free and uncongested streets and highways suggest a figure of some 6 million passenger trips per average weekday; allowing 1.8 passengers per car and assuming that on the average each trip will produce three records as it crosses the various zone boundaries, we arrive at a figure of about 300 million items per month to be processed. Actually, this figure might be reduced rather drastically by several factors: The charges being considered here would themselves act to reduce the number of car trips by diverting traffic to mass transit and diminishing the number of trips of minor importance; it might be considered superfluous to obtain and process the records relating to off-peak traffic, or the geographical extent or the number of zones might be smaller than that contemplated here, which involves a system that is probably larger than would be required in the immediate future. For the present, however, 300 million items will be used as the basis for the laying out of a maximal system, even though in the event only 50 million or 100 million items might have to be provided for. This involves about 100 full reels per month.

4. *Normal Processing of Data–Major Bulk Operations*

(*a*) *Initial sort.* The first processing step is to take the data relating to each segment separately, and sort these data so that they are in order first by vehicle identity number and then by time. For a typical segment generating eight reels of data per month, the sorting could be accomplished in four tape passes, assuming a moderately large computer, with 16 tape units and a core memory of either 8000 words of 36 bits or 6000 words of 72 bits. The first pass is an internal sort producing strings of about 4400 items; up to 512 of these strings are distributed over eight tapes mounted on tape units 9 to 16, 64 strings to a tape. An eight-way merge is then performed reading backward from these eight tapes, producing 64 strings of about 35,200 items each, distributed over the tapes on tape units 1 to 8, 8 strings to a tape. Another eight-way merge produces strings of about 280,000 items each, one such string on each of the eight tapes on tape units 9 to 16, and a final eight-way merge from these tapes produces a single string spread over the eight tapes on units 1 to 8. It should be possible to arrange the mounting, rewinding, and removal of the tapes so that there would be little or no delay to the computer from this source. Program read-in time should also be negligible. In most cases it should be possible to program the eight-way merges to operate within tape input-output times, or nearly so. It may not be possible to do this quite with the internal-sort program, but even with sorting routines now used for other purposes, the computing time would not be more than six or seven times tape-handling time, while programs specifically designed for this special problem might do very much better than this. At 5 minutes per full reel of tape (3.5 minutes plus a 40% margin), this would require $5 \times 10 \times 1100$ minutes of computer time, or about 900 hours per month. This must be modified slightly to take account of the fact that some segments will produce more than eight reels of data and will require more than four passes to get a complete sort; on the other hand many of the smaller low-traffic segments will require less than four passes. The picture may change considerably if limited-purpose units specifically designed for sorting become available, or if the use of computers capable of accepting inputs and delivering outputs on more than one tape at a time is considered.

(*b*) *Zone processing*. In this step a pair of tape units is assigned to each of the segments surrounding a given zone, and the sorted set of tapes relating to this segment is fed into the computer using these tape units alternately, and similarly for each of the other segments, there being in most cases about six segments forming the boundary of any given zone. The computer merges these tapes internally, considering the items in order of vehicle number and time. Where an inbound record is immediately followed by an outbound record for the same vehicle with a time difference of, say, 20 minutes or less, the computer will determine, from a table stored as part of the processing program for this zone, the number of units of highway use to be assessed in accordance with the points of entrance and exit, and either the time of day or the density of traffic reported, or possibly both. An output item will then be produced, consisting of the vehicle identification, time of entry, segment and location of entry, and the number of units of highway use to be assessed. This item should also fit within 72 bits; if necessary the 5 bits giving the time to seconds could be suppressed in favor of the bits indicating the assessment and the segment. The direction bit can also be suppressed, since this will be apparent from the next item relative to that vehicle.

If desired, the difference in time can be compared with the minimum allowable difference in time, and if the result is an indication of excessive speed, another item can be produced which will either access an appropriate automatic fine or produce a record for subsequent separate processing.

Where an entrance record occurs without an exit record within a time which would permit the two records to be considered parts of the same trip, or similarly with an exit record without an entrance record, an item can be produced assessing a charge on the assumption that the trip continues to the center of the zone, based on the entry point and the indicated traffic density or the time of day.

Each zone would be processed separately in this way, with an appropriate schedule of charges loaded into memory for the processing of the each zone. Each original item would be processed twice, once for each of the two zones on the opposite sides of the segment. The processing should be readily programmable with or close to tape time, so that we have here another $2 \times 1100 \times 5$ minutes, or about 180 hours of computer time per month. If we think of the average trip as generating three original items, this will become four items after this processing, one item covering the zone in which the trip originates, 2 items for the zones passed through, and a fourth for the zone of destination; accepting this as an effective average relationship, the original 1100 reels of data become 1500 reels.

(*c*) *Zone merge*. The items thus produced will be in vehicle and time sequence for each zone; the number of items will vary greatly from zone to zone. The data for the various zones must now be merged into four strings. This may be done, for example, by first merging the shorter zone strings together until there are altogether 24 strings; these can then be put through a six-way merge to produce the required four strings. The preliminary mergings would probably not involve more than about one-third of the total data; we thus have 2000 reels of processing at this stage, which at 5 minutes per reel gives 170 hours of computer time.

(*d*) *Final computation*. The four strings produced by step (c) are fed to the computer on four pairs of tape units. A master file of vehicle owners, listed in order of vehicle identification number, and containing the name and address of the owner, type of vehicle, status of the account, and whether or not the owner wants a fully itemized bill, is fed in on a fifth pair of tape units. An 11th unit feeds in payments, address changes, and other account changes. The principal output, on tapes 12 and 13 alternately, is a high-speed printed tape, organized to cause the printer to print five bills at a time across the width of the printer, each bill headed by name, address, and vehicle number, and followed by the account itemized to the extent requested by the owner: At one extreme a line for each zone traversed, with the point of entry, time of entry, and charge indicated for each zone (the time and place of exit can be seen from the succeeding entry); many will prefer an itemization giving two lines per trip, one for the starting zone and time, and one for the terminal zone and time; others may be content with a simple total amount due. The amounts, in each case, are computed by adding the number of highway use units given by the zone processing, and multiplying by a factor depending on the type of vehicle as designated in the master file. Tape units 14 and 15 receive the updated master file. Unit 16 receives a spillout of unmatched items, errors, corrections, and situations requiring special attention, for example, records relating to long-delinquent accounts, records of cars developing an excessive number of speed violations, cars "wanted" in connection with other violations, identification numbers not found in the master file, etc. If we allow for a master tape containing 2 million entries of 120 characters each, 6 entries to a block, or about 28,000 per reel, the master tape would run to something less than 80 reels; adding a comparable number of entries, mostly of 12 characters, for payments, address changes, and other transactions, brings the total number of reels to be processed at this stage to something less than 2200, or less than 190 hours of computer time.

(*e*) *Bill printing*. A high-speed printer printing 5 items on a line at 600 lines per minute has a nominal output capacity of 180,000 items per hour. However, not all bills will be of the same length, so that if the bill headings must be in horizontal alignment to register with the printing on the stock, many of the lines to be printed will be partially blank. This can be minimized by having the computer sort the bills into size classes, emitting the bill data in groups of five bills all within the same size class whenever such a set of five accumulates. This procedure will also reduce the amount of blank output tape space and economize computer time. Even so an allowance of some 30% must probably be made for blank space on the output tape and the printer, so that the preceding estimate of 190 hours of computer time for stage (d) should be revised upward to 250 hours, assuming that everyone wants a fully itemized bill. To the extent that automobile owners are satisfied with a bill itemized only by trips or possibly by days, or with an unitemized bill, this requirement would be reduced; it would probably be necessary to have the output from stage (d) contain at least an itemization by trips, even though this information is not printed, otherwise there would be no way of recovering this information at reasonable cost for a specific account in case of a complaint of overcharging.

If all bills are fully itemized, allowance for blank spaces, headings, and totals would bring the total number of items to about 400 million per month, requiring 2200 printer-hours per month, which could be handled by six units operating 21 hours per day on the average.

TABLE 1
Summary of Equipment Requirements

		Introductory installation		Probable requirement		Maximum requirement	
		Items per month	50,000,000		100,000,000		300,000,000
		Reels of input, monthly	165		330		1,100
		Average daily hours of active recording	14		8		24
Items of equipment	Unit cost ($)	Number	Cost ($)	Number	Cost ($)	Number	Cost ($)
Computer, type 1105	1,612,000	1	1,612,000	1	1,612,000	3	4,836,000
Tape-handling units	20,000	10	200,000	18	360,000	54	1,080,000
Paper to magnetic tape converter	80,000	2	160,000	4	320,000	12	480,000
Printers, high-speed (with buffers)	237,000	3	711,000	5	1,185,000	10	2,370,000
Response blocks	20	1,000,000	20,000,000	2,000,000	40,000,000	2,000,000	40,000,000
Interrogators	5,000	100	500,000	300	1,500,000	800	4,000,000
Buffers (magnetic disk)	2,000	100	200,000	300	600,000	800	1,600,000
Tape punches	800	1,000	800,000	3,000	2,400,000	3,000	2,400,000
Special document reader	200,000	1	200,000	1	200,000	2	300,000
Cameras and auxiliary equipment	5,000	100	500,000	200	1,000,000	300	1,500,000
Total			24,883,000		49,177,000		58,566,000

(*f*) *Recording of payments*. The simplest procedure, and a moderately satisfactory one, would be to punch manually the car identification number appearing on a bill stub and the amount of the payment onto a tape which would then be sorted to provide the transactions input to stage (d). The punching would require verification: a redundancy check could be added to the identity number at stage (d) above, and the amounts of the payments could be checked by the use of a group sum. A more elegant method would be to program the printer tape so that the printer would print a readable code pattern on the bill stub. On receipt of a bill stub and check, the clerk would merely check visually whether the amount of the check corresponded to that of the bill stub, and then feed the check and bill stub into a machine which would read the coded pattern on the bill stub, make a magnetic tape record of the payment, imprint the identity number and amount credited on the dorso of the check, and print a list and total for each batch of checks. It probably would not be practical to attempt to produce a punched bill stub either directly on the bill printer or separately for allocation with the bills. If 500,000 bills per month are processed (many of the cars on the master list making no congestion-generating trips during the month), this volume of business could probably be handled by a single machine of this type, even on a single-shift basis, given an arrangement whereby several clerks could feed the checks and stubs to it in rotating or interweaving fashion (see Table 1 for summary).

II. THE ECONOMIZING OF CURB PARKING SPACE—A SUGGESTION FOR A NEW APPROACH TO PARKING METERS

Uncontrolled parking of automobiles on the streets in large cities produces extremely unsatisfactory results both in terms of impeding the flow of traffic through the streets, and in causing would-be parkers to spend an undue amount of time and effort in finding a place to park and in making it in many cases impossible for persons who need to get to a given destination in a hurry to find a parking space within a reasonable distance of their destination. In addition, dense parking may make it difficult for trucks to make deliveries, may cause double parking for such deliveries, again impeding the flow of traffic, and may hinder the operation of street cleaning and waste collection. In some areas parked cars may constitute a hazard to children.

Some of these problems may be met by prohibiting parking at certain places and in certain periods. The more difficult problem is to devise a method of control at times and places parking is to be permitted, so as to ensure the economical utilization of such space. If this problem can be adequately solved, the remaining aspects of the parking problem can probably be taken care of by relatively simple adaptations. Accordingly, the following discussion will initially be limited to the control of parking where the only objection to the use of a given space by a given individual is that he may thereby be depriving someone else of the privilege of using it.

1. Present Inefficiencies

From the economist's point of view, the methods of control so far attempted are essentially types of rationing. Regulations typically limit the length of time an individual may park on any one occasion; such limitations may be imposed only during those periods of the day during which the space is in relatively heavy demand but often are in effect at all times. Such regulations are, almost necessarily, highly inefficient in the rationing of parking space. If no one would want to park more than the allotted time, the regulation has no effect, while if there is someone who has an urgent need to park for 2 hours, say, in a 1-hour space, he will be barred and have to go elsewhere to a less convenient spot, even though his need is greater and he would have been willing to pay much more for the privilege than would the two 1-hour parkers he might displace.

The situation is made worse by the fact that the permissible length of stay is almost always fixed at one uniform level during the entire period for which restrictions are in effect at all. This means that if the permitted duration of parking is short enough so that even during periods of heavy demand parking is adequately curtailed (between the exclusion of those who wish to park for a longer period and a higher turnover of short-period parkers) so that no would-be parker has to seek long for a space, then in periods of light demand within the period during which the limit applies, there will be many unused spaces which longer term parkers could use to good advantage if permitted to do so, at no inconvenience to others.

Ideally, it would be desirable to vary the time limit on parking with the time of day and between weekdays and holidays so that there would normally be a sufficient number of vacant spaces to make it unlikely that any large number of intending parkers would be unable to find a space within a reasonably short distance. Regulations of this sort, however, would probably prove almost completely unenforceable. Indeed, it is notorious that anything approaching strict enforcement of time limits on parking, as distinguished from complete prohibitions on parking at particular times, are extremely expensive to enforce, and are widely infringed nearly everywhere.

One possible modification of the usual parking limit rule would be to provide that even when a car has parked over the applicable limit, no violation will be considered to have taken place unless the 5 or 10 adjacent parking spaces are all occupied at some time after the expiration of the time limit, and no summons would be issued unless at the time it is issued the adjacent spaces are full. This would, in effect, mean that parking would be freely allowed as long as there remains parking space for others. The difficulty with this is that it would make violators of those who merely guessed wrong as to the number of other cars that would want to park in the vicinity in the period before they plan to return their car; to impose a fine or similar penalty on such persons would certainly produce considerable dissatisfaction.

Somewhat similar remarks apply to present types of parking meters as they are now employed. In most cases the function of the meter is simply to make the parking limit more enforceable. While to be sure a price is exacted for the use of parking space, this price is in most cases insufficient to be the prime rationing factor; parking in meter-controlled areas is restrained primarily by the greater degree of compliance with the time limit that can be secured. In some cases it is not legally permissible to park for a second consecutive period merely by putting another coin in the meter; however, it is doubtful whether such action would be proceeded against in any but the most flagrant case; it is the inconvenience, in most cases, of returning to insert additional coins in the meter that makes this practice insignificant.

Some meters, to be sure, can be arranged to take several coins at once, and thus to permit prepayment for various periods of time up to a given maximum. In most cases, however, it is still the maximum limit that is the effective restraint on parkers, and the only purpose served by the multiple-coin device is to abate the dissatisfaction that otherwise can arise with single-coin meters when short-time parkers are nevertheless required to pay for the full term. There is also the possibility that with single-coin meters parkers may waste time and congest traffic by looking for a meter that has some unused time still registered on it. There was recently a news story to the effect that a meter had been devised with a magnetic device that would trip back to zero when the car was driven away. On the whole, this seems to be an instance of misguided ingenuity: it does not seem that utilization of parking space would in any way be improved by the addition of this feature to the meters. Their only accomplishment would be to cajole a few extra nickels from the pockets of parkers into the public treasury. Even assuming that such devices are quite inexpensive and that they are free from such troubles as being tripped by someone swinging a pair of roller skates close to the meter, this would seem to be a very expensive way to raise revenue.

Thus, parking meters as presently used still fall considerably short of meeting the need for a method of economically controlling the use of parking space. Given a sufficiently restrictive maximum time limit, meters make it possible for short-term parkers to find space promptly, even during periods of heaviest demand. But at periods when demand is less heavy, they make it more difficult for longer term parkers to find space,

and indeed keep space from being used at all—not because of the payment required, but because of the relative certainty that overtime parking will be detected and penalized. On the other hand, if the time limit is made longer to avoid underutilization of space in periods of lighter demand, there will be congestion and inability to find space promptly during the peak periods.

Conceivably, a parking meter could be constructed that would run at different rates at different times of the day so that depositing a coin would prepay a varying period of parking, say 20 minutes during rush periods and up to several hours during other periods. The limit would then be adjusted, for various times of day and for various neighborhoods, so that in each neighborhood it almost never becomes very difficult to find a vacant parking place, and so that during the time when the deposit of a coin is required, the bulk of the parking places are in use. This would ensure that parkers would not be barred from the use of parking spaces by unduly short limits when parking space is plentiful, and, on the other hand, would ensure that short-term parkers, at least, would nearly always be able to find a place close to their destination and without too much searching. Parking space would thus be utilized as fully as it can be without making it unduly difficult, on occasion, to find an empty space. However, this scheme still leaves much to be desired. As a practical matter, it will be difficult to work out in detail the schedule for each group of parking meters so as to keep demand and supply in balance at all times. The mechanism would presumably not be too complicated if all that is necessary is a daily variation for weekdays, with restrictions, inapplicable on Sundays and holidays. But if the meter is required to vary the limit according to a different schedule on Saturdays, Sundays, and holidays, then either a fairly complicated mechanism is required or a fairly extensive servicing job is required to set the meters every time the schedule changes. More serious, it would probably be difficult for motorists to know or determine in advance how long they are permitted to park in a certain area at a certain time, and some irritation may be created through parkers getting into a space only to find when they come to examine the instructions on the meter that the currently applicable limit is insufficient for their purposes. Also, in common with all prepayment meters, and in fact with any strict time limit, it is not always possible for a parker to tell how long his particular business is going to take, and again a violation may result from merely making a wrong forecast of how long one is going to have to wait in someone's office.

But more fundamentally, though such a meter could ensure that parking space was as fully used as possible, subject to having some unused margin available, it is incapable of seeing to it that the space is used by those who have most need of it. For example, in a period of heavy demand it might be necessary to restrict parking to 20 minutes or half an hour in order to keep space available. This means that those who will need to park for only 20 minutes at a time can find parking space no matter how inconsequential their need, provided only that they are willing to pay the nominal meter fee, while those who need more than 20 minutes will have to go elsewhere, possibly at much greater inconvenience. For example, A may have several brief errands to do at slight distances from each other; A thus has a choice between parking for an hour or two on the fringes and walking from one place to another, or driving from one place to the next, parking briefly at each. Which A does may be a matter of relatively little importance to A. B, however, may be a stranger in town with a strictly limited amount of time, or may be pressed for some other reason, or may have heavy parcels to carry, or may be an invalid, or may be driving a carful of children, and may have an appointment requiring an hour or more. Parking close to his destination may be much more important for B than A, yet under any of the present meter arrangements, either the time limit is such that B cannot park at all for the necessary time, or the time limit is such that although it would be legal for B to park the required time if he could find a place, so many others come within the limit that all the space is taken and B is unable to find a space close at hand except by sheer good luck. It may of course be true that on the average it is preferable to have a space occupied three times by short-term parkers than by a single long-term parker, since in the former case within a given time three persons would reap the benefit derived from coming close to their destination, and in the latter only one. Nevertheless, what is true on the average is not true in particular cases, and in many instances it will be more important from every point of view to have the space occupied by a particular long-term parker rather than by the short-term parkers he would displace.

2. *Pricing instead of Rationing*

If such situations are to be dealt with economically, it will be necessary to abandon the rationing concept of parking control, and to adopt instead a concept of renting parking space to the parker in accordance with principles of the market in which demand is held down to the supply by means of the price charged. As applied to parking, this means allowing parkers to park as long as they wish (within ultimate limits of the order of 24 hours or more to facilitate dealing with abandoned vehicles and similar contingencies), subject to the payment of a fee commensurate with the time over which the car is parked and at a level so determined as to keep the amount of parking down sufficiently so that there will almost always be space available for those willing to pay the fee.

This will mean in many cases a substantial increase in the rates over those now in effect in most parking meter installations. Some indication of

what levels parking meter rates should be set at to adequately control parking is to be had by observing the rates charged for parking in parking lots. Such parking is for most purposes inferior to curb parking, assuming that the latter is readily available. Curb parking provides immediate access to the car, whereas in many parking lots considerable shuffling about is often necessary to obtain access to a given car. Curb parking in most cases can be nearer to the destination than a parking lot, which often may be two or three blocks from the destination. Indeed, if curb parking is adequately controlled by the meter charge, there should be space available within 100 yards or so of almost every destination at nearly all times. With curb parking there is less wear and tear on battery and starter from having the car shuffled about. While parking in a lot provides some supervision against theft, the fact that in most cases the keys must be left with the attendants provides an additional risk that probably offsets most of the disadvantage of curb parking in this respect. In some cases off-street parking provides heat and protection against the weather, but for the bulk of short-term parkers this appears to be a minor consideration. Yet, despite these advantages of curb parking, meter rates are almost always but a fraction of those charged in parking lots. Ten cents for 1 hour appears to be about the highest rate charged by meters, whereas it seems to be relatively rare for downtown parking lots to charge less than 25 cents; while this in some cases may be for the entire day, on the other end of the scale, downtown lots often charge as much as 75 cents for the first hour and 25 cents an hour thereafter. If the meter rate is to control parking without the imposition of a rationing limit, it would seem that curb parking rates would have to be higher than rather than lower than the rates for parking lots. In any case, the rates would vary considerably from neighborhood to neighborhood and from time to time; it would seem very likely that for a substantial part of the downtown areas of large cities the rate might have to go as high as 5 cents for each 15 minutes, or even higher, in order to keep the parking space from becoming preempted by the early birds.

With the rates set at such higher levels, and with meters made so as to vary the rate according to the estimated intensity of demand for parking space at various times of the day, a fairly good approach to economical utilization of the available parking space would in principle be attainable. In practice, however, there would be several difficulties with such a scheme. First, the use of prepayment meters would encounter considerable difficulty when the rate is so much higher and when there would be the possibility of depositing the fee for an extended period of parking. The difficulty for some of predicting how long they would be parked would be accentuated, and there would be stronger tendency to shave the estimate a bit close, with the correspondingly greater frequency with which violations would occur, with the result of either an increased enforcement load or an impairment of morale and a breakdown of compliance. Also, with a variable rate it would be more difficult for parkers to figure out how much they must deposit for any given period, with resulting confusion and dissatisfaction. To meet these difficulties it is necessary to devise some scheme which will permit the net payment to be determined at the end of the parking period, instead of requiring prepayment.

Perhaps an even greater difficulty, however, is that of adjusting the rates so that space in each neighborhood is fully utilized, but not overcrowded. Demand varies not only by time of day and by day of week, but seasonally; there are special occasions that do not fit into any regular pattern, and nonrecurring shifts in demand may also take place fairly rapidly. Even if an agency charged with the setting of the meter rates were to concern itself only with the regular recurrent patterns of use, it would have to have a rather substantial staff to analyze patterns of parking space use and to adjust the rates accordingly. This process would in many cases be subject to pressures by the various interests affected, and if the job was not done well the resulting pattern might appear wholly arbitrary to many, with a resulting lowering of morale and compliance.

3. *A Demand-Controlled Meter Rate*

The problem of determining the pattern of rates might be avoided almost entirely and a more flexible adaptation of charges to demand might be obtained by making the rate depend on the degree to which the parking space in a given neighborhood was being utilized at a given moment. This could be done, for example, by controlling a group of, say, 20 parking spaces from 20 corresponding interconnected parking meters. The meters could be arranged so that whenever more than, say, 3 out of the 20 spaces are vacant there would be no charge; whenever only 3 spaces are unoccupied, a slight charge would be made; the charge would become higher as more spaces are occupied and would be quite high if all of the spaces should become occupied. In this way there would be an automatic adjustment of the rate to variations in use.

With the rate dependent on the number of nearby vacancies, there would be an incentive for each parker to park insofar as possible in locations where demand is light, and there will be a natural tendency for the long-term parkers to park somewhat further away from the areas of heaviest demand, even if there is no variation in the nominal schedule of rates, since the effective rates will be lighter by reason of the larger proportion of vacant spaces. It will still be possible to vary the rates by appropriate regulation as between different areas, but the exact location of the boundaries between the different rate areas will not be so important, since the differentials in occupancy rates on either side of the

boundary will tend to bring the effective rates into approximate equality, with a general tendency of the effective rates to graduate downward as the distance from the congested area increases, in a much smoother manner than would be possible by regulation alone.

There will, to be sure, be an incentive for parkers to park in such a way as to keep the effective rate for themselves low by discouraging others from parking in the adjacent spaces. Some care will be needed in marking the spaces to indicate clearly the limits within which cars are to be parked, and penalties may need to be imposed in cases where cars are parked in such a way as to encroach on neighboring spaces.

With this scheme of automatically adjusting the rate, it becomes more than ever necessary to provide for some means of determining the charge when the parker leaves his space, since at the time he leaves his car in the space he will have no way of knowing for sure just what the charge will be for a given length of time. Fortunately, it appears possible to devise a reasonably simple scheme for postpayment meters.

4. *A Postpayment Meter*

Each meter will have an indicator, similar to those on present meters, but arranged to indicate to one side of the zero point the amount of the charge due and to the other side the amount of charge prepaid. There will also be a flag which will indicate when the meter is not in operation, also substantially similar to those on present meters. Coin slots will be provided, preferably for 5-, 10-, and 25-cent coins, possibly with a crank to register the coins as they are deposited. The essentially novel part of these meters would be three locks instead of the one now provided for collection purposes. One of these locks is designated as the parker's lock, identical for all meters; a second is the meter lock, distinctive for each meter; and a third is the servicing lock, identical for all meters, but, of course, different from the other two.

For the occasional parker it will be possible to operate the meter on the prepayment principle by merely depositing an appropriate number of coins and cranking them up, the amount being shown on the prepayment side of the indicator scale. The indicator then returns gradually to zero as time elapses at a rate dependent on the number of meters in operation in the interconnected group. Those who park more than a very few times in the area in which the plan is in effect, however, will find it to their advantage to obtain from an appropriate city office a parker's key, which will be identical in notching for all parkers, but will bear stamped on the handle the license number of the particular car in conjunction with which it is to be used, or perhaps a serial number by which the person or agency responsible for its use could be identified. The key could be issued for a fee of, say, 25 cents plus a deposit of, say, $5. The fact that it had been issued might perhaps be endorsed on the vehicle license, but this may not be necessary. The parker who has such a key can then proceed to any vacant parking space and insert his key in the lock and turn it, which will release the meter key from its lock, the meter key having been left in the meter when the space is not in use. The parker takes the meter key with him, and thus locks his own key in the meter. While the car is parked the meter ticks off the charge, and when the parker returns he deposits the indicated amount of money, cranking the indicator back to zero. When the indicator is back to zero, he will be able to insert the meter key and turn it in its lock, thus releasing his own key, which he takes with him to use on another occasion.

The parker's key will not be released until he has paid the charge and returned the meter key. Should the parker leave without paying the charge and recovering his key, he would, of course, forfeit some or all of his deposit. This would mean that the meter would no longer be operative until serviced. It would presumably be desirable to allow others to park free of charge in such a space until such time as the meter is serviced.

To make such a system work, there would, of course, have to be periodic checks to see that where cars are parked there is either a prepayment registered or a parker's key in the lock, bearing a license number corresponding to that of the car, though perhaps the check of license numbers could be omitted most of the time. Where a parker's key is observed in the lock with either no car or a car with a different license number in the corresponding space, the servicing key may be used to unlock the meter, remove the parker's key, and remove the meter lock cylinder and replace it with a different cylinder with its meter key in place. The meter key kept by the delinquent parker will thus no longer be effective. A return of $1 of his deposit might be offered for the return of this meter key.

While normally each key would be used only in conjunction with the car having the corresponding license number, some flexibility could be introduced by issuing with each key a placard showing the license number on the key, which placard could be placed on the inside of the window of the car when a car other than the normal one is parked with a given key. This would permit some flexibility in the accommodation of visitors and guests, and also at the time when license plates are changed.

Such a postpayment plan could, of course, be used either with meters with a preset schedules of rates or with rates controlled by the number of unoccupied spaces. With the preset schedule, each meter can be an independent unit, but would have to have a clock operating continuously so as to operate a cam or cams indicating the appropriate meter rate, in addition to the charging clockwork itself, which would have to be arranged to operate at different rates of speed, as indicated by the cams. Periodic winding and setting of the clock might become necessary, although arrangements might be made so that the normal amount of use of the meter would keep the clock wound as the crank is turned to register the coins.

If the rate is to be demand controlled, ideally the preferable arrangement would be to have about 20 meters, say, connected electrically in a group, with the rate controlled for the entire group by the number of vacant spaces. Electrical interconnection would permit each meter to be placed adjacent to the corresponding parking space. This arrangement, however, is likely to involve a fairly heavy expense for the interconnecting electrical conduits, which may or may not be felt to be worthwhile. Probably this arrangement would be suitable primarily for areas where the demand for parking is very heavy and where a substantial capital outlay becomes justified in terms of promoting efficient utilization of the parking space.

A less-expensive arrangement would be to mount the meters for a number of parking spaces together on a single standard and interconnect them mechanically, thus doing away with the need for electrical conduits. This, however, imposes limits on the number of spaces that can be put in a single group; in most cases if it were attempted to mount as many as 20 meters together, parkers might have an inconveniently long way to walk in order to operate the meter, checking of parkers' keys against the cars in the spaces would become more difficult, and more confusion is likely to arise as to which meter corresponds to which parking space. During the summer the painting of numbers on the pavement would serve fairly well to identify the space with the corresponding meter, but when there is snow on the ground, there would be difficulty. Possibly five to seven spaces is about as many as can conveniently be controlled together on this basis. The difficulty with having this few spaces in one control is primarily that the graduation of the rates becomes too abrupt. There is hardly any justification for a charge when as many as two out of seven spaces are empty; there would thus be only two rates; a low rate where six out of seven spaces are occupied, and a high rate when all seven spaces are occupied. If the rate is high enough so that even in periods of heavy demand there will not be an excessive amount of searching for a space, and if the low rate is low enough not to deter an undue number of potential parkers during periods of low demand, the gap may be considerable, and the results correspondingly erratic. But even so, it would seem that a degree of efficient utilization of curb parking space could be secured with this method that can hardly be approached by any other feasible method that has been proposed.