middle game. It is weak toward the end, but the authors believe that additions to the decision routine will remedy the situation. There are several other routines that could be expanded, such as defending pieces rather than moving them away when attacked. All of these are, however, demonstrable, and add little to the entire scope of the program. Self-adjustment routines are being considered, to change the value of parameters after the loss of a game, and to change the ordering in the decision routines, but these are still in the talking stage. While it is true that the machine makes the same move given in the same position, there are so many positions, that its play is not predictable in a new situation.

Applications of Digital Computers to Problems in the Study of Vehicular Traffic

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THE study of vehicular traffic on a scientific basis is still in its infancy. This is due to the enormity of the job. Currently, research in this area is carried on along two distinct lines. First, there is the approach which attempts to study traffic conditions in the small and gradually builds up to larger systems. This is an approach which may accomplish the desired goals, but from all current indications success in this area is distant.

The second approach is a study of traffic problems in the large, meaning a major metropolitan area. Clearly, the methods which are being used today are relatively crude; but constant research for new methods and improvement of the old ones has led to results which have been verified in actual traffic situations, and the predictions made have agreed remarkably well with the observed data.

The research reported in this paper is based on data obtained by the Detroit Metropolitan Area Traffic Study in 1953. At that time a survey of existing traffic conditions was made under the direction of Dr. J. Douglas Carroll at a cost of one million dollars. The survey consisted of three parts: First, a suitably large sample of the population of the metropolitan area was interviewed at home and information was obtained as to the origins and destinations, nature, and frequency of the trips which were made. Second, the major truck and taxi companies were consulted and the same kind of information was obtained from them. Third, roadside interviewing stations were set up and vehicles were stopped and drivers were asked the origin and destination and nature of their trips.

The metropolitan area which was studied included the city of Detroit and its suburbs, covering three counties, and extended far enough beyond them to include those areas which could reasonably be expected to play any part in the metropolitan Detroit area traffic picture at the end of the forecast period, which was set at 1980. The area was divided into 265 zones, and the survey data were expanded to give the total number of trips between any pair of zones for an average 24-hour period. These results were then checked by comparing actual traffic counts across screen lines against computed traffic volumes. It was found that the data obtained from the traffic survey were uniformly about 10% low, and suitable adjustments were made. Thus, an accurate picture of the existing traffic flow had been obtained and the data were presented in the form of a matrix of order 265.

The assumption was made that any trip which originated in the metropolitan area would retrace itself within a 24-hour period so that the matrix mentioned was symmetric with nonnegative integers as entries. Thus, the element \( a_{ij} \) of the matrix represents the number of vehicles which make a trip between zones \( i \) and \( j \).

The first problem which presented itself was the prediction of this matrix for some future date. It is well known that the trip generating characteristics of the given area depend on land use and on the population of the area. Thus, it was a relatively simple matter to predict the growth of the number of trips for each of the 265 zones. The difficult problem is the distribution of the total number of trips originating or terminating in a given zone over the remaining zones. There are a number of methods in use which attempt to cope with this problem, all of which are imperfect. The problem can be stated mathematically as follows: Given a real symmetric matrix with nonnegative integral entries, find a matrix of the same kind whose row sums are prescribed. Unfortunately, this mathematical problem does not have a unique solution. Its formulation thus must be revised to take into account the characteristics of traffic flow. All of the methods currently used operate in a similar fashion.

If the predicted trip volume between zones \( i \) and \( j \) is denoted by \( a'_{ij} \), then this quantity must be influenced by the growth factors \( g_i \) and \( g_j \) of both zones which are involved. Thus \( a'_{ij} \) must be multiplied by some mean value of the appropriate growth factors. In practice, \( a'_{ij} \) is multiplied by both growth factors, after which an adjustment is made by dividing the product, which is thus formed by some normalization factor, \( K \). The various methods employed differ in the choice of \( K \). Regardless of how \( K \) is chosen, the new matrix obtained by this process will not have the correct row sums. To obtain a matrix of the proper kind the process is repeated, and after a few iterations convergence is obtained. The methods used vary in the number of iterations required for convergence. The method used at this laboratory was developed by Dr. Carroll's staff and has become known as the Detroit Method. The number \( K \) in this method is obtained by dividing the sum of all matrix elements at the end of any iteration into the predetermined sum of the elements of the final matrix. This method has been improved upon by choosing \( K \) as that factor which will give the total matrix sum as prescribed at the end of any iteration. It is clear that this will accelerate convergence.

Regardless of which method was used, this explains how the traffic picture for the entire metropolitan area is predicted.

A new problem is the presentation of this large number of individual data elements in an easily comprehensible form. The accepted means of doing this is the so-called trip-desire map. This is a map of the area divided into areas of equal traffic density by means of isolines. Production of such a map involves a great deal of labor. The usual procedure can
be described as follows: The map of the
area is overlaid with a square grid pattern.
For each pair of zones a straight line
segment is drawn which joins the centers
of the two zones. The number of
vehicles making the trip from zone i to
zone j is counted for each square which
is intersected by the line segment just
described. This procedure must be
repeated for each pair of zones before a
trip-desire map can be constructed.

Trip-desire maps were constructed by
this method in 1954 and 1955 by using the
IBM (International Business Ma-
Chines Corporation) 604 computer.
The procedure used currently presents a vast
improvement not only in that much more
powerful computers such as the IBM 650
and 704 machines were used, but also in
the basic method of obtaining the maps.
The principal tool which has been adapted
for this purpose is the so-called Moore
algorithm, by which the shortest path
joining any two points of a network can
be found. This is accomplished within
a computer in the following manner: One
first chooses a node of origin and assigns
to all other nodes an essentially infinite
distance from the node of origin.
Thereafter, the procedure employed attempts to
reduce systematically these infinite dis-
tances by first replacing the distances of
the nodes immediately adjacent to the
node of origin by the actual distance and
proceeding in an iterative fashion.
When no distance can be reduced any
further, there is a number associated with
each node which represents the minimum
distance from that node to the node of
origin. To trace the shortest path from
any node to the node of origin the follow-
ing procedure is employed: The numbers
assigned to the nodes adjacent to the one
in question are compared with the num-
ber assigned to the node of destination to
find which adjacent node has a value
which differs from the value of the node
of destination by exactly the length of the
segment joining these two nodes. The
node thus found yields the first link of the
shortest path, and one proceeds in this
manner toward the node of origin. It is
for this reason that the final assignment of
values to all nodes is referred to as a
minimum tree. It will be recalled that a
tree is a linear graph containing no cycles
with the property that there is a unique
path joining any two nodes of the graph.
Clearly, to find the shortest path for all
pairs of nodes it is necessary to construct
a minimum tree for each node considered
as a node of origin.

Computer programs have been written
for both the IBM 650 and the IBM 704 to
find all shortest paths joining all pairs of
nodes for networks containing up to 99
and 1,000 nodes respectively. Trip-
desire maps can be constructed using the
Moore algorithm by replacing the square-
mile grid mentioned before by a network
whose nodes are the zone centers and
whose segments are the lines joining the
centers of adjacent zones. After all
shortest paths are found, it is a relatively
simple matter to assign the traffic volume
making a trip between any two zones to
the shortest path joining the respective
zone centers, thus obtaining a trip-desire
map which is essentially equivalent to the
one obtained by the older methods. It
took approximately three hours to obtain
the minimum paths for a network of 265
nodes on an IBM 704, and the assignment
of traffic volumes to these minimum paths
requires approximately two hours for
each trip-desire map.

The Moore algorithm is also of extreme
usefulness in the final problem reported
in this paper, which is the assignment of
traffic and the prediction of future traffic
densities on networks of streets and ex-
pressways. Of particular interest is the
prediction of street traffic on expressway
facilities as yet in the planning stage.
The procedure employed is the following:
For each pair of zones the distance and
time required to make the trip are com-
pared for a surface street route as well
as for a route utilizing the expressway net-
work. The latter involves determination of
the nearest ramp of entry of the ex-
pressway network as well as the nearest
ramp of exit and proper speed estimates
for the surface and expressway portions of
the trip. Empirical evidence has been
obtained which relates the percentage of
the number of vehicles making a given
trip which use the expressway system to the
time and distance ratios. Thus, the
number of vehicles using the expressways
can be predicted, and computer programs
have been written which simulate a traffic
counter on each link of the expressway
network. It is thus possible to obtain
the future distribution and density of
traffic on various proposed networks of
expressways.

The first such projection which actually
has been tested was performed at this
laboratory in the summer of 1956. The
problem concerned expected traffic loads
on the John C. Lodge expressway, which
was scheduled to be completed in the fall
of 1957. The results indicated that this
expressway would be overcrowded to such
an extent that traffic would be slowed
down considerably. Considering the na-
ture of the methods employed in this pre-
diction, the agreement of actual traffic
conditions on this expressway with the
predicted traffic densities is nothing short
of amazing. It is therefore somewhat dis-
turbing to look at the results of the
latest prediction, which forecasts the
traffic distribution on a much larger ex-
pressway network scheduled to be con-
structed within the next ten years. The
predictions show that this network will be
vastly overcrowded in 1980. What is
more important is the fact that although
these predictions cannot be viewed with
the degree of confidence of earlier predic-
tions due to the longer time involved,
these predictions do point out the loca-
tions which will present the greatest bottlenecks.

Thus, it is possible to modify the net-
work and reforecast future traffic distri-
bution of several alternative networks
until an optimal design is obtained. It
must be pointed out that these investiga-
tions are expensive and require large
amounts of expensive machine-time and
personnel. However, when one considers
that the cost of the projected expressway
network is in the vicinity of one billion
dollars, it does seem prudent to expend
time and effort in an attempt to optimize
such an expenditure.

The next problem to be solved is the
determination and forecasting of traffic
densities on the entire arterial network
of the metropolitan area. The diffi-
culties inherent in this problem are manifold.
First, and most important, there is the
magnitude of the system to be considered,
which transcends the capacity of cur-
rently available commercial computers.
Secondly, there are the difficulties caused
by the lack of knowledge of driver be-
havior. It is clear that the method em-
ployed to predict expressway traffic
densities is not suitable for the forecasting
of traffic densities on the entire arterial
network. The previous problem was
solved by recognizing that only a fraction
of the drivers making a given trip will use
the expressway network, while the
remaining portion will use the surface
route. Thus, it is not sufficient to com-
pute merely the shortest path joining any
origin and destination, but a variety of
paths must be computed and the traffic
volume distributed amongst these paths
according to some as yet undetermined
criteria.

The problem of computing several best
paths is considerably more difficult than
that of merely computing the shortest
path. Although this problem has been
investigated by another organization
which developed a computer program, the
procedure employed at this laboratory is
thought to be superior, primarily due to
the application of the following theorem:

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The (N+1)st best path is a deviation from some Kth best path where K > N.

A deviation from path P is defined to be a path which coincides with path P from the destination for a number of links which might be 0, which then contains exactly one link joining a node of path P to a node which is not on path P and which then proceeds to the origin via the minimum tree. This theorem makes it possible to write a computer program which will economically find an arbitrary number of ranked best paths. Once these paths have been determined on the basis of distance alone, they will be examined for various other attributes which may have an effect on the frequency with which drivers will choose them. A partial list of such attributes is the following:

1. Travel time.
2. Number of intersections.
3. Number of turns.
4. Capacity of the links in the path (mean, maximum, minimum).

Clearly, some empirical tests will have to be made to determine a function of the criteria listed which could be used to determine route selection of drivers. Considerable numerical experimentation in comparison of computed results with the existing traffic conditions is being planned.

With the advent of better and faster computers, it seems highly possible that in the not-too-distant future, road planning will become an exact science.

The Role of the Digital Computer

in Mechanical Translation of Languages

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The problem of applying digital computers to the mechanical translation of languages is currently receiving world-wide attention. Projects are under way at three or four major universities and research centers in the United States; others in England, Italy, and Russia. Of particular interest to military intelligence, the problem is emphasized by the increase in communication speed relating one language to another. It becomes more and more difficult to find experienced translators with the specialized knowledge in various fields of science and technology that is required for adequate translation and to provide an interchange of knowledge regarding the progress made in different areas of the world. The vast quantity of this material to be translated lends urgency to the development of some high-speed means of translation. An obvious means of satisfying this need lies in the application of high-speed digital and logical equipment. The solution of the mechanical translation problem by means of digital computers is one of continuing importance and extreme interest to those who would follow unique and interesting digital computer applications.

As is true in many computer application problems, the most difficult and frustrating element of machine translation is the definition of the means of approach and the structure of the problem itself. In resolving this aspect of the solution, skilled linguists must necessarily play an extremely important part. Language is formed by usage; formed organically developing a complex hierarchy of rules. Although the rules are inviolate, they are extremely difficult to specify and bring to conscious realization. At the University of Washington, the MT (Mechanical Translation) Project has progressed by means of closely coordinated efforts between the linguistic and engineering members of the staff. The work, in many respects, has followed the familiar research and development pattern; theoretical development has been followed to a certain point, the method is automatized and tested, then analysis of results yields further advances upon the theory.

The mechanical translation problem can be easily stated. It is necessary that a high-speed means be found to provide accurate and intelligible translation from one language to another. The MT project at the University of Washington deals with translation of general technical literature from Russian to English. The problem can be grossly divided into two parts. A computer memory or dictionary must be available for use in the translation process. The dictionary output must then be logically processed to provide a clear output translation.

The requirement of a dictionary or lexicon is obvious. The need for logical processing of the dictionary output is evident when the form of a normal dictionary output is considered. A saving of both logical and other grammatical problems, the raw dictionary output is one that may be accurate; but the intelligibility is subject to considerable interpretation.

Dictionary Storage

Most groups working with the mechanical translation problem are approaching the computer application from the standpoint of using available general-purpose digital computers with their associated storage facilities as the translation dictionary. While this may be acceptable from the criteria of performance and output, the access to memory for a large-scale dictionary scanning process is one involving considerable time; and the magnitude of the dictionary itself may be seriously limited by available storage space. The University of Washington group has based their operation upon the use of the high-speed photoscopic memory developed specially for this application by the International Telemeter Corporation. This memory device has a permanent storage of $30 \times 10^6$ bits with a random access time on the order of 0.05 second. The magnitude and speed of the memory has several significant implications on the basis of dictionary content.

The contents of the translation dictionary is something that is subject to several approaches. If the dictionary memory is seriously limited in size, it is sometimes considered advisable to dissect words into stems, endings, and prefixes; using logical operations to assemble the related parts of a single word into the target language. In cases when memory limitations are not considered, a saving of both logical and