"THE INFLUENCE AND FUNCTION OF THE ELECTRONIC COMPUTER IN BRIDGE DESIGN"

B. C. Fairchild and F. E. Staten
Computer Programming Team, Bridge Division
Kentucky Department of Highways

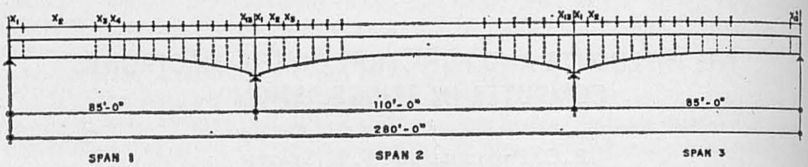
I think it is very appropriate that we are assembled on the campus of our State University to discuss a matter of profound significance to both educators and practicing engineers. The necessity of meeting the obligations of a tremendous "Federal-Aid Highway Program" has given birth to automation in the performance of engineering computations. This automation has been made possible by devices known as electronic computers, and by the ability of some of our fellow engineers to write programs for these machines. One was first used by a state highway department about three years ago. Today, 42 or more state highway departments and an even larger number of highway engineering consulting firms are using computers in their day-to-day operations. Such progress is remarkable. It stands as a tribute to the unity of the highway engineering profession and to the willingness of state highway departments and consulting firms to pool their efforts for the common good. We can all feel proud of this accomplishment.

Although computers have attracted widespread interest and are being used extensively, they still represent something new and strange to many of us. How are engineers, as a group, reacting in this case? Are they enthusiastic? Are they eager to accept and use computers? Too many engineers are still answering "no" to these questions. Why is this? It is simply because of the element in human nature that causes us to distrust or even resent those things we don't understand. History provides us with many similar examples, such as the airplane and the automobile. A more recent example has been the reluctance of many engineers to accept the use of photogrammetry in highway engineering work. The electronic computer has not enjoyed exception to this behavior pattern. One state highway department had to issue an executive order to get its engineers to use the computer. Of course, hindsight is easy, but let's see if we can't justify some foresight in this case. Is it necessary that we understand the purpose or function of each circuit or tube included in the complex make-up of the internal workings of a computer? Of course not. This is the manufacturer's problem, not ours; and, I might add that the manufacturer has been handling this problem very well.

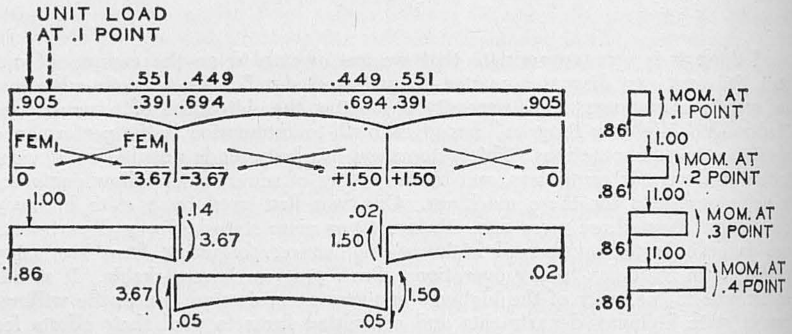
There are at least eight different makes of computers being used in the highway engineering field. In Frankfort, we are using the IBM general purpose digital computer. The Administrative Services Division is the custodian and the principal user; however, it is available to all divisons of the highway department. At present, other users include the Bridge Division and the Design Division.

This machine has been designed with a high degree of reliability. In addition to this reliability, there are many internal, automatic checking features. The basic philosophy of these checks is that nothing is taken for granted. All functions and data in the machine are represented by the presence of electronic signals —never by the absence of a signal. In addition to these checks, any properly written program will include mathematical logic checks—to insure that the data is being processed in the desired manner.

Are you still wondering if we really need to concern ourselves with adapting this tool to suit our particular purposes. The answer is obvious. We do. If we didn't, the work of the past three years simply would not have been done. As previously stated, the necessity of meeting the obligations of our Federal-Aid Highway Program brought about the use of computers in our field. Even before



Benson Creek Bridge



this, there was an apparent need for improving the procedures used in the preparation of construction plans. Now, let us classify the needs which a computer can satisfy. These fall into three main categories:

(1) The need for relief from the obligation of performing routine mechanical computations for hour after hour: A chore which has often inspired a search for more interesting employment; a chore which has robbed us of our time for creative effort. We became engineers because of the creative desires in our make-up, not to perform as robots.

(2) The need for an ability to make more thorough design analysis. We can now investigate numerous assumptions or trial conditions in less time than we were previously capable of making one analysis. As designers, we have often been required to sacrifice too much to satisfy a time schedule. A structure designed in haste often represents excess costs of thousands of dollars. Such a structure, when erected, stands as an embarrassing monument to our limited capacity to do a proper job. These cases adversely affect the personality and reputation of the engineer. Computers can help us to eliminate the majority of these cases.

(3) The need for an ability to apply more exact design techniques to those cases which merit such consideration. As design engineers, we often encounter such problems, but are usually faced with the reality that such an approach is too costly or time consuming. Computers can change this. An example of this is published in this month's *Civil Engineering* magazine. This example involves the stress analysis of a large radar antenna. In this problem, both the joint displacements and the bar stresses were required for several sets of loads. The time required to perform a rigorous analysis of the three dimensional framework by conventional methods would have been prohibitive on the basis of both calendar time and man hours. The members of the structure are so arranged that the external reactions are statically determinate, but the structure is internally redundant to the 19th degree. The computer was programmed to perform the analysis by the stiffness matrix method. This project was accomplished at M.I.T. by two of the structural engineering professors.

INSTRUCTIONS TO ENGINEER
SPAN: Number span left to right and write span number in block.
G: Number the trial girder and write girder number in block.
PROJECT NO. : Use project number of job. Use only numbers.
SPAN LENGTH: Use length of span under consideration. Span length is 3 digits + 2 decimal digits.
MINIMUM I : Use true I values. Decimal must be consistant for all values needed Use minimum value in bridge.
NO. OF INC. : Number of increments in which span is divided. 14 is maximum number.
X_1, X_2---X_{14}: Length of increments; cannot exceed 3 digits + 2 decimal digits. First increment must be less than .1 span. Increments do not need to be equal.
I_L & I_R: True I values left and right of each increment. Decimal point consistant with minimum I value.

CONTINUOUS BEAM CHARACTERISTICS

KENTUCKY DEPARTMENT OF HIGHWAYS
DIVISION OF BRIDGES

County__________ Name__________

Date__________

Checked by__________ Phone__________

INSTRUCTIONS KEYPUNCH OPERATOR
COLUMN 10: Indicates card number.
CARD 1: Blanks in columns 11,12,18,19 and 29 through 80.
CARD 2,3 AND 4: No blanks.
Over-punch never required.
SPANS: Enter total number of spans.
SYM. SPANS: Enter 8's for spans symmetrical about their own centerlines. Enter 9's in the remaining spaces

SPAN NO. ______

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

SPAN	G	PROJECT NO.		SPAN LENGTH	MINIMUM I	NO. OF INC.	SPANS	1 2 3 4 5 — SYM. SPANS
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SPAN	G	PROJECT NO.		$X_1 < L/10$	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}
1			2														

SPAN	G	PROJECT NO.		I_L	I_R	I_L	I_R	I_L	I_R	I_L	I_R	I_L	I_R	I_L	I_R	I_L	I_R
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SPAN NO. ______

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

SPAN	G	PROJECT NO.		SPAN LENGTH	MINIMUM I	NO. OF INC.	SPANS	1 2 3 4 5 — SYM. SPANS
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SPAN	G	PROJECT NO.		X_1 L/10	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}
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SPAN	G	PROJECT NO.		I_L	I_R	I_L	I_R	I_L	I_R	I_L	I_R	I_L	I_R	I_L	I_R	I_L	I_R
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SPAN NO. ______

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SPAN	G	PROJECT NO.		X_1 L/10	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}
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SPAN	G	PROJECT NO.		I_L	I_R	I_L	I_R	I_L	I_R	I_L	I_R	I_L	I_R	I_L	I_R	I_L	I_R
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Don't ask me to explain this problem, I just wanted to cite an example to fit this category; where the computer can satisfy the need to use more exact methods or can enable us to do things which just simply were not possible without computers. I also want to emphasize that it is this category, which to date, has received the least attention. Most programs, now in operation, instruct the computer to do essentially the same things that we would do using a desk calculator. There are two good reasons for this:

(1) It was felt that engineers would be more prone to accept computer methods if they did things in the standard manner to which he was accustomed.

(2) This was probably the easiest and more expedient way to get the job of programming done, and, the more programs we have to use, the more benefit we can obtain from our computers.

Now that educational institutions are experimenting with computers, we can begin to expect more programs that exploit this third need category. I am certain that work in this field will enable us to make some valuable revisions to our specifications, which govern our design procedures. The ability to investigate a broader scope of conditions, using more exact analysis procedures, will certainly produce a more reliable basis on which to specify design limitations and design assumptions. There is an IBM 650 computer located on this campus and I'm sure we will be hearing more about this as time goes by.

Do we eventually get all our problems programmed, and then sit back and let the machine do our work? No, this is absurd; the computer is only a tool or an aid for the engineer. It is not now capable, nor will it ever be capable of acquiring an ability to think or reason, based on four years of college education and years of experience.

On what basis can we select men capable of writing programs that make these machines do our work for us. A paper presented at the Southern Association of State Highway Officials, October 1, 1958 conference, had this to say: "It seems essential that the potential programmer should:

(1) have formal education and experience directly related to the field of work for which he will be primarily responsible for program preparation. A sound background in basic mathematics is a prerequisite;

(2) be an exacting person;

(3) be systematic and neat;

(4) be persistent and capable of long periods of concentration;

(5) find satisfaction in 'mental work';

(6) be able to meet a problem as a challenge and not be easily distraught.

"A period of professional instruction follows the careful selection of a person that is to become a programmer. This training is usually provided by the computer manufacturer. Some colleges and universities are now offering similar courses. The effective programming of all problems depends upon the capability of the programmer. The type and complexity of the program that he can develop will be determined by his education and experience, and earnestness of effort. He may often be assisted by other qualified persons in certain specialized fields, but he will do a much better job if he is generally self-sufficient."

Mr. Frank Staten will now explain the function of the computer in the design of a continuous beam bridge. After this, I will have some further comments, and then we will have a question and answer period.

Because of the cost and time involved in writing computer programs, all state highway departments and some consultants have agreed to pool their individual efforts and to make available to any member of their pool programs resulting from these efforts. The Beam Characteristics and Moment Distribution Programs are two such programs. The first was obtained from the Nebraska Highway Department, the latter from the Washington Highway Department. The Nebraska Beam Characteristics Program has been modified by us to meet the need of the Bridge Division, and the output format has been changed so as to be compatiable as input into the Washington Moment Distribution Program.

JOB NO	SPAN	P @	V LT	V RT	M @ LT	M @ .1	M @ .2	M @ .3	M @ .4	M @ .5	M @ .6	M @ .7	M @ .8	M @ .9	M @ RT
000	1	1.1	86	14-	0	728	607	485	363	242	120	1-	123-	245-	0367-
000	1	1.2	72	28-	0	610	1220	980	740	499	259	19	221-	461-	0702-
000	1	1.3	59	42-	0	497	995	1492	1139	786	434	81	272-	625-	0978-
000	1	1.4	46	54-	0	394	787	1181	1574	1118	661	205	252-	708-	1165-
000	1	1.5	36	65-	0	302	604	905	1207	1509	961	412	136-	684-	1233-
000	1	1.6	26	74-	0	223	445	668	890	1113	1336	708	81	546-	1174-
000	1	1.7	18	82-	0	155	310	465	620	775	930	1085	390	305-	1001-
000	1	1.8	11	89-	0	97	194	291	389	486	583	680	777	24	0729-
000	1	1.9	05	95-	0	46	92	138	184	230	275	321	367	413	0391-
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000	1	3.6	06	06	0	48	95	143	191	238	286	334	381	429	0477
000	1	3.7	05	05	0	40	80	119	159	199	239	278	318	358	0398
000	1	3.8	03	03	0	29	57	86	114	143	171	200	228	257	0286
000	1	3.9	02	02	0	15	30	45	60	75	90	105	120	135	0150
000	1	3.4	06	06	0	48	97	145	193	242	290	339	387	435	0484
000	1	3.5	06	06	0	50	101	151	202	252	303	353	404	454	0505

JOB NO	SPAN	P @	V LT	V RT	M @ LT	M @ .1	M @ .2	M @ .3	M @ .4	M @ .5	M @ .6	M @ .7	M @ .8	M @ .9	M @ RT
000	2	1.1	05	05	0367-	315-	264-	212-	160-	108-	57-	5-	47	98	0150
000	2	1.2	09	09	0702-	603-	504-	406-	307-	208-	109-	11-	88	187	0286
000	2	1.3	13	13	0978-	840-	703-	565-	428-	290-	153-	15-	122	260	0398
000	2	1.4	15	15	1165-	1001-	837-	673-	509-	344-	180-	16-	148	312	0477
000	2	1.5	16	16	1233-	1059-	885-	712-	538-	364-	190-	16-	157	331	0505
000	2	1.6	15	15	1174-	1008-	842-	677-	511-	345-	179-	14-	152	318	0484
000	2	1.7	13	13	1001-	860-	719-	577-	436-	295-	154-	12-	129	270	0412
000	2	1.8	09	09	0729-	626-	524-	421-	318-	215-	113-	10-	93	196	0299
000	2	1.9	05	05	0391-	336-	281-	226-	171-	115-	60-	5-	50	105	0161
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000	2	2.9	07	93-	0233-	153-	73-	6	86	166	246	325	405	485	0536-
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JOB NO	SPAN	P @	V LT	V RT	M @ LT	M @ .1	M @ .2	M @ .3	M @ .4	M @ .5	M @ .6	M @ .7	M @ .8	M @ .9	M @ RT
000	3	1.1	02-	02-	0150	135	120	105	90	75	60	45	30	15	0
000	3	1.2	03-	03-	0286	257	229	200	172	143	115	86	58	29	0
000	3	1.3	05-	05-	0398	358	318	279	239	199	159	120	80	40	0
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000	3	1.5	06-	06-	0505	455	404	354	303	253	202	152	101	51	0
000	3	1.6	06-	06-	0484	436	387	339	291	242	194	145	97	49	0
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000	3	1.8	04-	04-	0299	269	239	209	180	150	120	90	60	30	0
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000	3	3.6	54	46-	1165-	709-	252-	204	661	1117	1574	1180	787	393	0
000	3	3.7	42	59-	0978-	625-	272-	80	433	786	1139	1491	994	497	0
000	3	3.8	28	72-	0702-	462-	222-	18	259	499	739	979	1219	609	0
000	3	3.9	14	86-	0367-	245-	124-	2-	120	241	363	484	606	728	0

Obtaining influence line ordinates and demonstrating the use of these programs can best be demonstrated by comparison of computer computations to manual computations. The design calculations for the Benson Creek Bridge at Frankfort will be used for the comparison. The structure is a reinforced concrete, variable depth, three-span bridge, designed by the Kentucky Bridge Division. The computer computations will be compared to the results of manual computations by Mr. Leonard Engstrom. Mr. Engstrom did the major design work for this bridge.

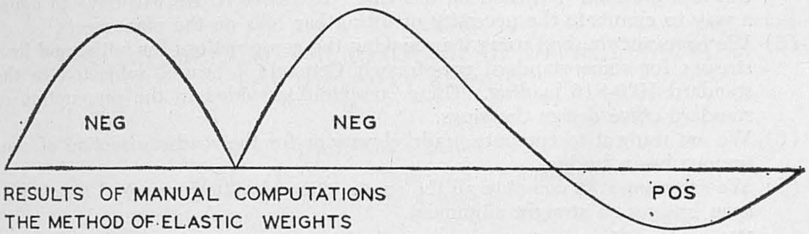
Slide one shows the girder that was selected for this bridge. As we all know, design of a continuous, variable depth girder is more properly called a problem of analysis. A trial-girder is chosen based on economy factors and past experience with similar field conditions. The girder is then analyzed and if it is not suitable, it is modified and the analysis starts over. It is evident that it is highly desirable to choose a correctly proportioned girder the first time; this is not always possible. Sometimes a week of work is lost when a girder will not meet the design requirements, or perhaps due to special considerations, a girder that is over-designed is used. The computer, as the Bridge Division is now using it, has not eliminated the trial-girder method, but many of the time consuming computations have been eliminated by providing influence line ordinates for these trial-girders.

The Beam Characteristics Program, using the Moment-Area Principle and working with one span at a time, computes stiffness factors, carry-over factors and fixed-end moment values for a unit load placed successively at the tenth-points of the span. Slide two shows the data sheet that is used to supply the information necessary for the computation of these factors.

This data is processed in the following manner. Data for span one is read into the computer. The stiffness factors, carry-over factors and fixed-end moment values are computed and stored in tabular form in computer memory. The next span is then solved in a similar manner and stored. The process is repeated until the computer recognizes it has processed all spans. The table is then examined for spans that are symmetrical about their own centerline. Factors that should be identical with each other are averaged together. If the difference in the factors is larger than could result from accumulative rounding error, the computer stops and indicates the reason for the stop. A stop of this type would indicate an error in the mathematical description of the girder. If no errors are encountered, stiffness factors are used to compute distribution factors and fixed-end moment values are divided by span length to obtain moment coefficients. All factors are then punched into cards that will be used as input to the Washington Moment Distributions Program.

The Washington program will distribute fixed-end moments for any single story, continuous frame structure with up to fifteen spans. This program will also compute influence line ordinates for a structure with up to five spans. The girder may be or may not be integral with the piers. Influence line ordinates for moment are computed for the tenth-points of every span and at each support. Influence line ordinates for shear are provided for every span at the supports. Information required for input is the distribution coefficients and carry-over factors, fixed-end moments if they are to be distributed, and span lengths and load to be used if influence line ordinates are to be computed. When influence line ordinates are to be computed, a table of fixed-end moment coefficients must be supplied only if the girder is non-prismatic. The value of this program to the Bridge Division without the Beam Characteristics Program is limited because most of the continuous beams designed by our office are variable depth beams. This was the reason which prompted us to obtain both programs and to make them work together to obtain the end results—influence lines for moment and shear.

Using results from the Beam Characteristics Program, influence line ordinates are computed in the following manner. As shown by slide three, the fixed-end moments for a unit load placed at the one-tenth point in span one is distributed through the structure. Once the moments of continuity are known, the structure becomes determinate.



RESULTS OF MANUAL COMPUTATIONS
THE METHOD OF ELASTIC WEIGHTS

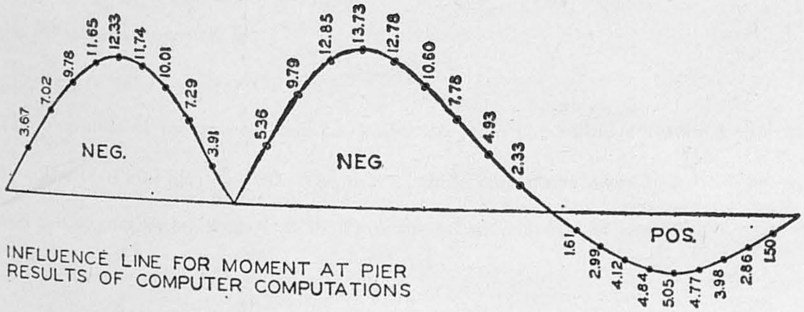
The moment at every tenth point in the structure is found by reducing the span to a series of free bodies. When all moment values for this loading are computed, the results are punched. The process is repeated with the unit load placed at the two-tenths point in span one. The same computing procedure is followed and the results are punched. In this manner, the unit load is moved completely across the girder. The punched cards are then sorted to provide a suitable listing of the influence line ordinates. Slide four shows a listing of the ordinates obtained for the Benson Creek Bridge.

Slide five shows the influence line for moment at the pier as a result of manual computation and computer computation. The percentage difference between the results is quite small. I do not say error because both are correct based on data used, and because of the type solutions used it is impossible to say one is more correct than the other. The shear ordinates can be combined to give influence lines for reaction at the piers.

In concluding, the point I would like to stress is not that computers will replace the engineer, nor am I stating that the methods used for solution of influence line ordinates are the best, but rather to show the type problem that is best adapted to computer solution. As engineers, we have two choices; we can accept the computer as a powerful tool for the benefit of the profession, or we can resist it as an infringement on our personal ability. The profits from which we can come from electronic computation depends on the choice we make.

Thank you, Frank. Now let me briefly list the other purposes for which our office is using our computer.

(1) We use it to compute the geometrics for bridges composed of simple spans on a horizontal curve alignment. The end walls may or may not be skewed and a vertical curve can also be included.
(2) We use it to compute perpendicular offsets from a chord or a tangent line to a circular arc.
(3) We use it to evaluate the design properties of a reinforced concrete T-beam, or rectangular beam, having from one to four rows of tension steel.
(4) We can use it to extend and sum up individual bar bill totals and combined totals, such as for the substructure on a bridge. I say we can do this, because



INFLUENCE LINE FOR MOMENT AT PIER
RESULTS OF COMPUTER COMPUTATIONS

this is a program that died on the vine. To revive it, we will have to figure a way to eliminate the necessity of listing bar bills on the plan sheets.

(5) We have just finished using it in making the computations for initial and final stresses for some standard pre-stressed Concrete I beams, subjected to the standard H20-S16 loading. These computations aided in the preparation of standard office design drawings.

(6) We are using it to compute grade elevations for the roadway section of continuous beam bridges.

(7) We are using it to compute all the construction elevations required for simple-span bridges on straight alignment.

We are working on a program to condense the construction elevations just mentioned to a tabular form, thus eliminating the necessity of entering them on the plan sheets by hand.

We have also done considerable work on a program to compute all the construction elevations needed for simple-span bridges on curved alignment. We need to finish this program and also to work on one to do the same job for continuous beam bridges. The problem, in this case, is to get the deflection computations set up.

There are many other useful programs that have already been worked out by others, which we hope to obtain and put to use.

In conclusion, I wish to emphasize that the largest obstacle in the way of progress is still the passive acceptance of the computer by many of the persons who can benefit most by its use. They do not openly oppose it, but do not willingly cooperate and encourage computer programs. I'm sure, however, that the day in which we seek to use the electronic computers, rather than manual methods, as naturally as we seek to ride rather than walk, is not too far off.