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TOWARD COMPUTERIZED UNDERWRITING— A BIOLOGICAL AGE MODEL

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ABSTRACT

This paper presents a theoretical basis for a computerized methodology for estimating biological age—a measure of time to death. The authors then discuss their attempts to reproduce the human underwriting of one life insurance company using a computerized methodology.

I. INTRODUCTION

Competition within the life insurance industry seems to increase consistently with time. In order to achieve the lowest possible costs for their products, life insurance companies must pursue diligently all possible avenues for reducing expenses.

In the past thirty years, computer technology has assisted greatly in reducing costs in many insurance company operations. This paper will assert that it is now feasible to computerize much of the underwriting process, and, with continuous monitoring of the computerized system, not sacrifice any significant level of underwriting accuracy. This would lower underwriting costs significantly and shorten the time from application to issue of the policy.

II. A BIOLOGICAL AGE MODEL

In determining the premium to be paid for life insurance, or a life annuity, the actuary is concerned with time to death. This is clear from the mathematical formulation of the net single premium functions:

For life insurance:

$$\bar{A}_x = \int_0^\infty v^t \, {}_tp_x \, \mu_{x+t} \, dt \, . \tag{1}$$

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For life annuities:

$$\bar{a}_x = \int_0^\infty \bar{a}_{\overline{t}|}\, {}_tp_x\, \mu_{x+t}\, dt \,. \tag{2}$$

Several decades ago, the underwriter carefully analyzed each application according to his best estimate of time to death before assigning an appropriate premium to it.

Over the years, as rates of mortality declined, and as the cost of medical information and the underwriting process rose, more policies were issued on a nonmedical basis. For these policies, the only factors affecting the premium are sex and chronological age, or time since birth. Chronological age may be an important factor in predicting time to death, but it has been argued [3] that a high correlation with chronological age is neither a necessary nor a sufficient condition for an index that accurately measures time to death.

Instead, several biostatisticians have turned to a concept called biological age as a superior way to present, in a single parameter, the best estimate for time to death. If a risk is assigned a biological age x, that risk has a life expectancy, $\mathring{e}_x$, which corresponds to the life expectancy of the average member of the defined group whose chronological age is x. That is, someone assigned biological age 45 will have the same life expectancy as the average of a group of people whose chronological ages are 45. Therefore a biological age model is nothing more than a disguised statement of life expectancy. The reason for this method of statement will be explained later.

Several studies on the estimation of an index of biological age are listed in the References.

The Framingham Study of 1973,[1] an epidemiological study of cardiovascular disease, has been used in the development of the biological age model. The general framework of this study can be described as follows. At the start of the study period, measurements on k variables are taken on n individuals deemed free from disease. After a period of m years, the individuals are reexamined and the n_1 individuals who have developed the disease in the interim are noted. Based on these data, it is desired to estimate $P(x_1, x_2, \ldots, x_k)$, the probability that an individual with measurements $(x_1, x_2, \ldots, x_k)$ will develop the disease in m years. A model to estimate this probability, suggested by Cornfield [7], has been used extensively in the analysis of such data: If $P(x_1, \ldots, x_k)$ represents the

[1] For example, T. Gordon and W. B. Kannel, "The Framingham Massachusetts Study: Twenty Years Later." In I. I. Kessler and M. L. Levin (eds.), *The Community as an Epidemiological Laboratory: A Casebook of Community Studies*, pp. 123–46. (Baltimore: Johns Hopkins University Press, 1970).

probability of developing the disease given measurements $(x_1, \ldots, x_k)$ at the beginning of the study, then

$$P(x_1, \ldots, x_k) = \frac{pf_1(x_1, \ldots, x_k)}{f(x_1, \ldots, x_k)} \tag{3}$$

and

$$1 - P(x_1, \ldots, x_k) = \frac{(1 - p)f_0(x_1, \ldots, x_k)}{f(x_1, \ldots, x_k)}, \tag{4}$$

where $f_0(x_1, \ldots, x_k)$ and $f_1(x_1, \ldots, x_k)$ represent the initial densities of characteristics in the populations subsequently found to be healthy and diseased, respectively; $f(x_1, \ldots, x_k)$ represents the unconditional distribution; and p represents the unconditional probability of developing the disease. Thus from equations (3) and (4),

$$P(x_1, \ldots, x_k) = \left[1 + \frac{(1 - p)f_0(x_1, \ldots, x_k)}{pf_1(x_1, \ldots, x_k)}\right]^{-1}. \tag{5}$$

If f_0 and f_1 are assumed to be multivariate normal with the same variance-covariance matrix Σ and means μ_0 and μ_1, respectively, then

$$P(x_1, \ldots, x_k) = \left[1 + \exp\left(-\alpha - \sum_{i=1}^{k}\beta_i x_i\right)\right]^{-1}, \tag{6}$$

where[2]

$$\alpha = -\tfrac{1}{2}(\mu_1 - \mu_0)'\Sigma^{-1}(\mu_0 + \mu_1) - \log\left[(1 - p)/p\right] \tag{7a}$$

and

$$(\beta_1, \beta_2, \ldots, \beta_k) = (\mu_1 - \mu_0)'\Sigma^{-1}. \tag{7b}$$

When the unknown parameters are replaced by their estimates, the resulting estimates of α and β_i are

$$\hat{\alpha} = -\frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{k}(\bar{X}_{1j} - \bar{X}_{0j})S_{ij}^{-1}(\bar{X}_{1i} + \bar{X}_{0i}) - \log(n_0/n_1), \tag{8a}$$

$$\hat{\beta} = \sum_{j=1}^{k}(\bar{X}_{1j} - \bar{X}_{0j})S_{ij}^{-1}. \tag{8b}$$

[2] Note: the prime (') in these equations denotes the transpose of the matrix.

These may be recognized as the estimated linear discriminant function coefficients with $\alpha = c - \log(n_0/n_1)$ (see, for example, [12]). Thus, under the assumptions of multivariate normality with equal variance-covariance structure in both populations, the model and estimates of the parameters are well defined. Of course, the imposed structure is rarely justified since the measured variables will include binary data (such as positive family history of heart disease) and markedly nonnormal data (such as number of cigarettes smoked per day). However, the form of the model (see Fig. 1) is intuitively a reasonable one for estimating risk, since it ranges from zero to one and increases rapidly over the middle portion of the range. Hence, the model attempts to find the linear function of $(x_1, \ldots, x_k)$ that places the healthy individuals at the "zero" end of the curve and the diseased individuals at the "one" end. Interactions among risk factors can be modeled by including appropriate product terms in the set $(x_1, \ldots, x_k)$.

Estimates of α and $(\beta_1, \ldots, \beta_k)$ when assumptions of normality are not made (but the form of the model is assumed) may be obtained by maximizing the likelihood function

$$L(\alpha, \beta_1, \ldots, \beta_k) = \prod_{j \in U_0} [1 - P_j(x_1, \ldots, x_k)] \prod_{j \in U_1} P_j(x_1, \ldots, x_k)$$

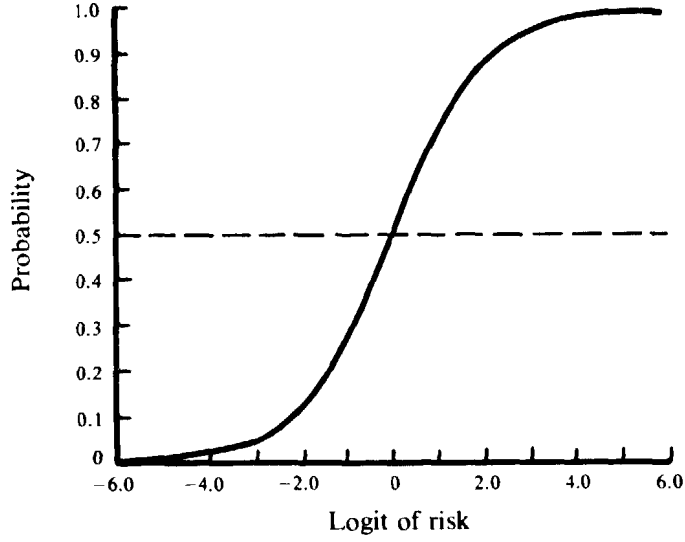


FIG. 1.—Graph of the logistic function used to estimate the risk of developing cardiovascular disease; that is, the probability P is given by $P = [1 + \exp(-LR)]^{-1}$, where LR is the logit of risk.

for α and $(\beta_1, \ldots, \beta_k)$, where U_0 and U_1 represent the sets of individuals in the healthy and diseased populations respectively, and $P_j(x_1, \ldots, x_k)$ represents equation (6) evaluated at the values of $(x_1, \ldots, x_k)$ observed for the jth individual. The maximum likelihood estimates often do not differ significantly from the linear discriminant coefficients and the latter often are used because their calculation does not involve iteration.

Such problems often involve a large number of independent variables. It is common to attempt to determine an "optimal" subset of these variables; that is, a relatively small number of the independent variables that may predict risk nearly as well as the entire set.

The importance of any variable, say the lth (for example, systolic blood pressure), for predicting risk may be investigated by maximizing $L_1(\alpha, \beta_1, \beta_2, \ldots, \beta_l = 0, \ldots, \beta_k)$. The ratio $-2 \log [L_1(\tilde{\alpha}, \tilde{\beta})/L(\hat{\alpha}, \hat{\beta})]$, where $(\tilde{\alpha}, \tilde{\beta})$ is the vector of estimates under the second model and $(\hat{\alpha}, \hat{\beta})$ is the vector of estimates under the full model, is asymptotically χ_1^2 under the hypothesis $\beta_l = 0$, and large values of this quantity indicate evidence against the hypothesis that the lth variable is unimportant in predicting the development of the disease, after adjusting for other variables.

These types of tests form the basis for stepwise procedures for model building. That is, variables can be entered into models one at a time so that each successive variable entered is the one that increases the likelihood function the most, given the variables previously accepted. The procedure stops when no variable that is not in the model increases the likelihood appreciably. Such procedures can be combined with variable elimination procedures, which remove variables one at a time until the removal of any variable in the model would decrease the likelihood appreciably. These stepwise procedures have been used extensively to try to determine "optimal" subsets of independent variables; however, they recently have come into considerable criticism (e.g., [9] and [10]). With the development of high-speed computers and numerical methods, it is possible to screen a great many of the models very quickly and determine which might be suitable candidates for consideration for an optimal model. The program SMOD, as described in [10], does this model screening, and was used in the analysis described below.

One advantage of developing adequate models of risk, other than the ability to test quantitatively for significant predictor variables, is that they may be used to prepare convenient summary tables such as Table 1. Such tables allow a physician to inform the patient of his personally estimated risk of developing disease and to determine which factors are elevating this risk. Further, when this is combined with a table such as Table 2, the physician is able to present the individual's risk relative to individuals

TABLE 1

PROBABILITY PER 1,000 OF DEVELOPING CARDIOVASCULAR DISEASE* IN THE NEXT EIGHT YEARS BY SPECIFIED CHARACTERISTICS

SERUM CHOLESTEROL	PROBABILITY PER 1,000 FOR 45-YEAR-OLD MALE†						
	Systolic Blood Pressure						
	105	120	135	150	165	180	195
	Nonsmokers						
185	22	27	35	43	54	68	84
210	28	35	43	54	68	84	104
235	35	44	54	68	84	104	129
260	44	55	68	85	105	129	158
285	55	68	85	105	129	158	192
310	68	85	105	130	158	192	232
335	85	105	130	159	193	232	277
	Smokers						
185	38	47	59	73	91	112	138
210	47	59	73	91	113	138	169
235	59	74	91	113	139	169	205
260	74	92	113	139	170	206	247
285	92	113	139	170	206	247	293
310	114	140	170	206	248	294	345
335	140	171	207	248	295	356	401

SOURCE.—Framingham Study, sec. 28, *The Probability of Developing Certain Cardiovascular Diseases in Eight Years at Specified Values of Some Characteristics* (Washington, D.C.: United States Department of Health, Education, and Welfare, 1973).

* In the Framingham definition, cardiovascular disease is considered to have developed if there is a definite manifestation of coronary heart disease, intermittent claudication, congestive heart failure, or cerebrovascular accident in the absence of a previous manifestation of any of these diseases or rheumatic heart disease.

† Probabilities are estimated using the model

$$P(x_1, \ldots, x_8) = \left[1 + \exp\left(-\hat{\alpha} - \sum_{i=1}^{8} \hat{\beta}_i x_i\right)\right]^{-1},$$

where $\hat{\alpha} = -19.7709560$ and

i	$\hat{\beta}_i$	x_i	i	$\hat{\beta}_i$	x_i
1	.3743307	age	5	.5583013	cigarettes (0, nonsmoker; 1, smoker)
2	−.0021165	(age)^2	6	1.0529656	LVH-ECG (0, none; 1, present)
3	.0258102	SC	7	.6020336	GI (0, absent; 1, present)
4	.0156953	SBP	8	−.0003619	SC times age

experiencing "average" (or perhaps, with some modification to the table, "ideal") risk.

Table 2 is based on Robbins and Hall's [13] approach to preventive medicine, called "health hazard appraisal." In this system, an individual's chances of dying from a number of diseases are computed, based on his physiological measurements, lifestyle, and so forth. These are combined and the composite risk is compared with the risk of death experienced by an "average" member of the population. The individual's appraised age, the age of the average individual with same risk of death, is obtained in this way together with recommendations aimed at reducing the ap-

TABLE 2

APPRAISED AGE OF INDIVIDUAL WITH SPECIFIED CHARACTERISTICS

SERUM CHOLESTEROL	APPRAISED AGE OF 45-YEAR-OLD MALE*						
	Systolic Blood Pressure						
	105	120	135	150	165	180	195
	Nonsmokers						
185	36	37	39	40	42	44	46
210	37	39	40	42	44	46	49
235	39	40	42	44	46	49	52
260	40	42	44	46	49	52	55
285	42	44	46	49	52	55	60
310	44	46	49	52	55	60	70
335	46	49	52	55	60	70	73
	Smokers						
185	39	41	43	45	47	50	53
210	41	43	45	47	50	53	56
235	43	45	47	50	53	56	63
260	45	47	50	53	56	63	71
285	47	50	53	56	63	71	74
310	50	53	56	63	71	74	75
335	53	57	63	71	74	75	77

NOTE.—The appraised or risk age is the age of the average Framingham Study (1973) male with the equivalent risk of developing cardiovascular disease in the next eight years by the same characteristics as specified in Table 1 (GI absent, LVH-ECG negative).

SOURCE.—Brown and Forbes [3].

* Calculations were based on the following average risks (see sec. 28 of the Framingham Study)

Age	35	40	45	50	55	60	65	70
Risk per 1,000	18	41	75	115	159	193	212	229

and risks of approximately 0 per 1,000 and 1,000 per 1,000 at ages 0 and 105, respectively. The appraised age was estimated by an average quadratic logistic interpolation procedure; results at ages over 70 were obtained by extrapolation from the arbitrary values given above, and should be treated with caution.

praised age. Since most persons appreciate the consequences of being, say, five years older than they are chronologically, the message is presented more effectively than if the same information were expressed as a probability. In this way, individuals appraised as being "older" than their chronological age may be encouraged to reduce factors that are elevating risk, and those appraised as "younger" may have their positive lifestyles reinforced.

A similar "health hazard appraisal" model is used by Health and Welfare, Canada, in their "Evalu-Vie" program. The input to the computer program consists of coded answers to the risk factor inquiry detail shown in the Appendix.

Thus, a biological age index may be seen as a function of a set of observable quantities, each of which makes an important contribution to the prediction of age at death, years until death, or some other measure stratifying the population by risk subgroups.

A biological age index, y, then may be written in the form

$$y = f(x, V, I, \Delta) ,$$

where y represents, for example, age at death, years until death, reduction in optimal lifespan, or an individual's appraised or risk age; x is the chronological age; V represents the additional contribution (adjusted for chronological age and other variables in the function) of the absolute level of a set of variables such as blood pressure, cigarette smoking habits, and family history; I represents the additional contribution of the interaction of variables in V with other variables in V and with chronological age; and Δ represents the additional contribution of past changes in any of the variables in V, and also of changes in variables that are not in V but are important because a change in them implies an elevation or reduction of y. The variables in the sets V and Δ and all constants entering into this function have to be determined from a study of a reasonably large number of individuals followed longitudinally.

III. A COMPUTERIZED UNDERWRITING EXPERIMENT

Mutual Life of Canada graciously granted the authors the opportunity to test the biological age model by attempting to computerize its underwriting process.

Mutual Life presently issues about 80,000 individual life insurance policies a year. Approximately 75 percent of these policies are issued nonmedically. Even for these policies, the cost of underwriting and issue

averages close to $100 an application and the time needed for underwriting averages around five days.

Mutual Life provided coded data on its adult nonmedical applications, including the following information:

1. Beneficiary relationship;
2. Insurance amount;
3. The underwriter's decision (issue standard, issue rated, or decline); and
4. If the decision was other than standard, other information that was requested by the underwriter.

It also provided the answers given to the nonmedical application form as shown in Exhibit 1.

The most serious problem was that there was little or no matching between the nonmedical questions asked by Mutual Life and the questions used in the currently available biological age models. Hence, it was impossible to enter the Mutual Life data into any of the prepackaged biological age models.

Instead, it was decided to access two sets of underwriting data. Each set would consist of approximately eight hundred applications. The first set of applications would be used to build a model that could discriminate between those applicants who were rated or rejected and those applicants who were issued standard without further information. The model developed from this first set of applications then would be used with the second set of applications to see if the model could discriminate correctly between those applicants who safely could be issued insurance at standard rates with no further underwriting and those who could not.

The first group of applications was used to build a model of the type described earlier, where, in this instance, $P(x_1, \ldots, x_k)$ is the probability that an individual with variables $x_1, \ldots, x_k$, corresponding to information from the application, will be judged substandard or rejected. Then

$$P(x_1, \ldots, x_k) = \left[1 + \exp\left(-\alpha - \sum_{i=1}^{k} \beta_i x_i\right)\right]^{-1},$$

where $(x_1, \ldots, x_k)$ represents responses to a set of k items chosen from the questionnaire, and the β's represent the weights attached to the items.

The model was built from the data on 824 applications, representing approximately one month's adult nonmedical receipts. Ten of these applications were issued on a substandard basis and seventeen were rejected. For the purposes of these analyses, these twenty-seven policies

EXHIBIT 1

The Mutual Life Assurance Company of Canada / Waterloo, Ontario

APPLICATION PART 2 - EVIDENCE OF INSURABILITY

To be used only if the Life Insured has attained 16 years of age (18 years in Quebec)

1 Name in full (print) _____ Date of birth _____ Sex _____

2 **A** Name and address of usual medical adviser (if none, so state) _____

B When and why last visited? _____

C What treatment was given or medication prescribed? _____

3 Are you now under observation or taking treatment? If yes, give details _____

4 Have you ever been treated for or ever had any indication of disease specify which:	YES	NO
A Disorder of eyes, ears, nose or throat?		
B Severe headaches, dizziness, fainting, loss of consciousness, fits, epilepsy, speech disorder, paralysis, stroke, nervous breakdown, mental trouble, or other disorder of nervous system?		
C High blood pressure, palpitation or pain about the heart or chest, difficult breathing, cardiac asthma, angina or coronary disease, rheumatic fever, heart murmur or other disorder of heart or blood vessels?		
D Persistent cough or hoarseness, coughing of blood, asthma, pleurisy, bronchitis, tuberculosis or other disorder of the lungs?		
E Ulcer of stomach or duodenum, recurrent indigestion, jaundice, gall stones, colitis, bleeding or other disorder of stomach, gall bladder, liver, intestines or rectum?		
F Sugar, albumin or blood in urine, venereal disease, kidney stone or colic or any other disorder of kidney, bladder, genital organs, breasts or disorder of pregnancy		
G Arthritis, gout, rheumatism, sciatica, deformity or disorder of joints, limbs or back?		
H Cancer or other tumor, enlarged glands or skin disease?		
I Diabetes, thyroid or other endocrine disorder?		
J Any illness, disease or operation not mentioned above?		
K Female life: Pregnant? (If so, give expected delivery date.)		

Details of yes answers:
Identify question number. Circle applicable terms. Include diagnosis, treatment, dates, duration and names and addresses of all attending physicians and medical facilities.

5 Do you now or have you ever used alcoholic beverages?
If yes, complete following questions.
A Frequency of use (daily, weekly, monthly)
B Amount consumed on each occasion
C Date last used
D Any treatment for alcohol use (including AA membership)
E Any motor vehicle impaired driving convictions

6 *Have you smoked cigarettes or marijuana in the past 12 months?*

Give daily use of	1-5	6-10	11-25	over 25
Cigarettes				
Other forms of tobacco				

If discontinued when and why?

7 Have you ever used heroin, morphine, other narcotics, barbiturates, amphetamines, or psychoactive (marijuana, LSD, etc.) drugs except as prescribed by a physician?

8 *Other than as stated in above questions specify if you have:*
A Been a patient or advised to have a diagnostic test, hospitalization or surgery in a clinic, hospital, sanitorium or medical facility
B Used the service of any other physicians in the last 5 years

9 Have you ever had	YES or NO	DATES	WHY TAKEN?	RESULT	NAME AND ADDRESS OF PHYSICIAN ORDERING INVESTIGATION
A An electrocardiogram?					
B Any blood tests?					
C Any X-rays? SPECIFY					

10 Has an application for insurance or annuity on your life ever been declined, rated or modified in any way? Yes ☐ No ☐ When? _____ Why? _____ Company? _____

11 Have you applied for or received a pension or compensation because of illness or injury?

	Yes	No	Give Details
	☐	☐	

12 Height (in shoes) _____ ft & ins / cm

Did you measure? Yes ☐ No ☐

Weight (in use clothing) _____ lbs / kgs

Did you weigh? Yes ☐ No ☐

Weight change in past 12 months: Gain _____ Loss _____
Reason _____

DECLARATION: I declare the above answers and statements are full, complete and true and shall form part of the evidence of insurability in respect of my application for insurance or for reinstatement of or change in my present insurance in The Mutual Life Assurance Company of Canada.

AUTHORIZATION: I authorize any physician or practitioner who has observed me for diagnosis or treatment, and any hospital, clinic or other medical or medically related facility where I have been a patient, and any insurance company, the Medical Information Bureau or other organization, institution or person that has any records or knowledge of me or my health, to give full particulars thereof including any prior medical history to the Mutual Life Assurance Company of Canada or its reinsurers. A photostat of this authorization shall be as valid as the original.

Signed at _____ **Date** _____

Witness _____ **Signature of Life Insured** _____

3-11-81

EXHIBIT 1—*Continued*

COMPLETE THIS SECTION FOR PARAMEDICAL AND MEDICAL EXAMINATIONS

12 Height (in shoes) _____ ☐ ft & ins ☐ cm Did you measure? YES ☐ NO ☐

Weight (house clothing) _____ ☐ lbs ☐ kgs Did you weigh? YES ☐ NO ☐

Weight change in past 12 months Gain ____ Loss ____ Reason

13 Girth of bared chest Girth of abdomen

Males only: full inspiration _____ at umbilicus _____ full expiration _____

14 Blood Pressure (sitting – without rest or exercise) Repeat at end of examination if over 140/90

READINGS	FIRST	SECOND	FINAL
Systolic	mm	mm	mm
Diastolic (at cessation of sound)	mm	mm	mm

15 A Pulse Rate _____

B Effect of exercise (twenty rapid toe touches or equivalent)

	BEFORE EXERCISE	IMMEDIATELY AFTER	TWO MINUTES AFTER
Pulse rate per minute			
Extra systoles per minute			

16 **Urinalysis** (Haemaconibistix Method)

Glucose Neg ☐ Pos ☐

Protein Neg ☐ Pos ☐

Blood Neg ☐ Pos ☐

ONLY Send urine sample to Head Office if any test is positive

Date mailed _____

ADDITIONAL REPORT BY MEDICAL EXAMINER

17 **Any evidence of past or present disease of:** (Please comment fully on any abnormal finding.)

	YES	NO
A Nervous System? (reflexes, coordination, tremors, etc.)	☐	☐
B Head and Neck?	☐	☐
Ears? – deafness, discharge, hearing aid, etc.	☐	☐
Eyes? – blindness, retina, etc.	☐	☐
Mouth? – including throat	☐	☐
C Heart and blood vessels? – Examine in erect and recumbent position before and after exercise. Complete section 18 if any abnormality is found.	☐	☐
D Chest and Lungs? Examine on bare chest with expiratory cough	☐	☐
E Abdomen? Liver, spleen, abnormal masses, tenderness, hernia – reason for surgical scar	☐	☐
F Genito-Urinary System? (include prostate)	☐	☐
G Musculoskeletal System? – include spine, joints, deformities)	☐	☐
H Endocrine System? – include thyroid, breasts)	☐	☐
I Skin – xanthomas, nevi, etc? Lymph nodes?	☐	☐

18 A Is there a murmur in the (if more than one, describe below as no. 1 and no. 2)

Erect _____ YES or NO Recumbent _____ YES or NO Left lateral position _____ YES or NO

Timing	Intensity	Quality	Location
Systolic	Faint	Soft	Mitral
Pre Systolic	Moderate	Blowing	Aortic
Diastolic	Loud	Rough	Pulmonic

Transmission beyond valve area Yes No

B Does exercise produce Shortness of breath Palpitation Pain No Distress

C Does exercise cause the murmur to Increase Decrease Disappear Remain the same

D Do you consider the heart enlarged? Yes No

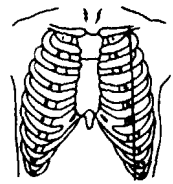
E Please locate Mid-clavicular line

Apex by X

Area of murmur by dotted outline

Point of greatest intensity by O

Transmission by →



F Is there a history of streptococcal or specific infection? Yes No

G What is your diagnosis?

19 How long have you known the person examined? Is the person examined a patient? Yes ☐ No ☐ Is appearance unhealthy or older than stated age? Yes ☐ No ☐

Has applicant to your knowledge ever abused the use of alcohol or been addicted to drugs? Yes ☐ No ☐

Do you know of any facts bearing on the risk which are not brought out by the foregoing questions? Yes ☐ No ☐ If yes, give details below

Was examination completed in your office? Yes ☐ No ☐ Did you require an interpreter to question the person examined? Yes ☐ No ☐

ADDITIONAL REMARKS

Signed at **Date** , at A.M. P.M.

Signature of Examiner

were grouped into one category, called the nonstandard group. Further, the analysis emphasized only the health-related information from the questionnaire.

Initially, simple summaries comparing the responses of the standard group and the nonstandard group to each of the medical-based questions from the application were prepared. These analyses indicated certain questions for which the response pattern was different in the two groups. Second, as an overall measure of the status of the applicant, a single variable, the number of "no" answers to certain questions, was created. Finally, guided by the results of these preliminary analyses, the model screening program (SMOD; see the earlier description) was used to identify subsets of the questions that would separate the two groups almost as well as the large number of original questions. This latter procedure had to be carried out in steps. At each stage, different combinations of items from the questionnaire were entered into a full model and those items which did not appear to make any significant contribution to the prediction of the nonstandard cases were deleted.

This process finally produced two models that seemed to be able to discriminate between standard and nonstandard lives nearly as well as the full set of independent variables. The variables in these models were the following (the question numbers refer to Exhibit 1):

Model 1	Model 2
Response to question 8A	Alcohol use
Response to question 9B	Cigarette smoking
The number of "no" answers	Response to question 8A
Age	The number of "no" answers
	Age

While the models seemed to predict equally well, there were some anomalies in that responding "yes" to question 8A and to the questions on alcohol use and cigarette smoking increased the estimated probability of being judged standard. (Those patterns also were apparent in the original data: a higher proportion of standard lives drank, and a higher proportion smoked.)

With the maximum likelihood estimates of the coefficients in the model, it was possible to estimate, for each subject, his or her chance of being judged standard. By assigning a standard classification to any applicant with an estimated probability of being standard in excess of a chosen cutoff level, it was possible to assign each applicant to one of the four cells in the summary table below (Table 3).

TABLE 3

RESULTS OF CLASSIFICATION BASED ON THE MODEL

MODEL CLASSIFICATION	ACTUAL RATING		
	Standard	Nonstandard	Total
Standard	n_{00}	n_{01}	
Nonstandard	n_{10}	n_{11}	
Total	797	27	824

Thus, in the table, $n_{00} + n_{11}$ cases are correctly classified, while $n_{10} + n_{01}$ are incorrectly classified. By varying the cutoff level it is possible to increase or decrease the number predicted to fall in the standard class. For the purposes of this illustration, the cutoff level 797/824 = 0.9672 was chosen, as this produced small values of n_{01} with reasonably small values of n_{10}. In practice, one could choose a cutoff level that reduced the size of n_{01} at the expense of increasing n_{10} by assessing the costs of misclassifying a standard as a nonstandard against the costs of the other misclassification (that is, the extra cost of underwriting standard cases balanced against missing a nonstandard case). Alternatively, full traditional underwriting could be required for a chosen percentage of cases with the lowest estimated probabilities of being standard.

When applied to the original data set, using the cutoff level 0.9672, the two models were able to discriminate as shown in Table 4.

Thus, using Model 1, only 15.9 percent (131/824) of the cases were misclassified, but, most importantly, only 2 nonstandard cases were misclassified as standard. Increasing the cutoff to 0.975 resulted in only 1 nonstandard case being misclassified as standard, but 151 standard cases were classified as nonstandard. This one nonstandard case could not be correctly classified with a cutoff level as high as 0.99. (Further investigation revealed that this case was rated nonstandard on the basis of special

TABLE 4

RESULTS OF CLASSIFICATION FOR MODELS 1 AND 2

MODEL CLASSIFICATION	ACTUAL RATING					
	Model 1			Model 2		
	Standard	Nonstandard	Total	Standard	Nonstandard	Total
Standard	668	2	670	681	4	685
Nonstandard	129	25	154	116	23	139
Total	797	27	824	797	27	824

TABLE 5

RESULTS OF CLASSIFICATIONS BASED ON MODELS 1 AND 2 FOR THE SECOND DATA SET

MODEL CLASSIFICATION	ACTUAL RATING					
	Model 1			Model 2		
	Standard	Nonstandard	Total	Standard	Nonstandard	Total
Standard	680	0	680	684	0	684
Nonstandard	139	10	149	135	10	145
Total	819	10	829	819	10	829

information on the applicant's arthritis, gout, and rheumatism obtained from X-ray examination.) Model 2 did not fare quite so well, misclassifying fewer cases overall, but missing 4 out of 27 nonstandard cases (3 out of 27 using a level of 0.975).

It is well known that regression models often predict considerably better for the data set on which they were built than for other similar data sets; but in testing these models on the next 829 applications coded, as indicated in Table 5, both models were able to identify correctly all 10 nonstandard cases! Model 1, using a cutoff point of 0.9672, misclassified 139 standard cases as nonstandard, while Model 2, with the same cutoff level, did marginally better, misclassifying 135 standard cases.

Thus, Model 1 would have declared 680 applications as standard, leaving only 149 (18 percent) to be underwritten in the usual way. This could have resulted in significant savings in the cost of underwriting, balanced against an additional expense of approximately $0.62, the cost of computer time to use the model to classify the 829 applications.

As pointed out earlier, Mutual Life issues nearly 80,000 individual life insurance policies a year. Seventy-five percent of these are issued nonmedically, with an underwriting and issue cost of around $100 each and processing time of close to five days. Only 3.5 percent of the nonmedical applications are rated or declined, on average.

IV. CONCLUSION

Considerable work remains to be done in building a suitable discrimination model. However, it has been shown, through the use of a fairly crude model, that a computer program can produce results very close to those determined by human underwriters. This was done using input data not designed for computerization or based on any preconceived model such as the biological age model.

A great deal of the underwriting that is being done in an expensive and relatively slow manner today could be computerized. This would require

using a machine-readable application form with input more suited to the existing biological age models, although the latter may not be essential.

One of the exciting prospects of a computerized underwriting model is that it can reassess itself continuously. For example, every time a policyholder dies, the computer can retrieve the application form for the policyholder and determine what information was provided that might have predicted that early (normal, or late) death. In this manner, the computer can statistically reanalyze the weights that have been given to each input parameter and improve its own program continuously.

With this computerized model, a much more refined pricing stratification than exists today is possible. No longer will 75–85 percent of all cases be priced according to sex and chronological age only. Rather, the computer will determine the time to death in its program and set the proper premium level accordingly.

This same methodology, applied to life annuities, would be responsive to the feminists clamoring for unisex annuity mortality tables, since companies no longer would be pricing on the basis of sex and chronological age only. Rather, they would be using an objective statistical prediction as to time to death.

One can visualize a day, in the not-too-distant future, when an agent will enter the client's home with his portable computer terminal. After using the terminal as a sales aid (to show cost comparisons and investment attributes) the agent will ask the client the usual application questions. The answers to these questions will be entered into the computer through the portable terminal and, in a matter of seconds, the computer will tell the agent whether his client has been accepted or rejected, or whether further information is required. (The term "rated" no longer will be used.)

If the client is accepted, the computer will calculate the price level for the coverage requested based on the statistical analysis of time to death. Then, if the client is in agreement, the portable terminal will print out a policy and the process will be complete!

V. ACKNOWLEDGMENTS

The authors would like to thank the Mutual Life of Canada and, in particular, Barry J. Triller (new business executive) and Wilhelmina Gould (new business analyst) for their assistance with this project. Without their help, this research could not have been completed. We also would like to acknowledge the assistance of Evan Kelly, who was responsible for the computer analysis.

APPENDIX

HEALTH HAZARD APPRAISAL

RISK FACTORS: DETAIL AND CODES

Factor	Abbreviation	Code	Description
Sex	SEX	1	Male
		2	Female
Age	AGE		Enter age in years.
Alcohol habits	ALCOHOL	1	41 or more drinks per week*
		2	25–40 drinks per week
		3	7–24 drinks per week
		4	3–6 drinks per week
		5	1–2 drinks per week
		6	Stopped: stopped drinking (person has stopped before symptoms of cirrhosis). Factor should be given to stopped drinkers regardless of amount.
		7	Nondrinker: Never been a drinker
Arrest record	ARREST RECORD	1	Burglary, robbery, assault
		2	Without violence or threat
		3	No arrests
Weapons	WEAPONS	1	Carries
		2	Does not carry
Depression	DEPRESSION	1	Often severely depressed
		2	Seldom or never severely depressed
Miles per year	MILES		Enter miles driven per year and/or miles as an auto passenger.
Seat belt use	SEAT BELT	1	Worn less than 10% of the time
		2	Worn 10–24% of the time
		3	Worn 25–74% of the time
		4	Worn 75–100% of the time
History of bacterial pneumonia	PNEUMONIA	1	Has had
		2	Has not had
Blood pressure, systolic (if unsure enter 120)	BP: SYSTOLIC		Enter systolic blood pressure in mm.
Blood pressure, diastolic (if unsure enter 80)	BP: DIASTOLIC		Enter diastolic blood pressure in mm.
Blood cholesterol (if unsure use 2)	CHOLESTEROL	1	Cholesterol level 280+
		2	Cholesterol level 220–279
		3	Cholesterol level 219 and below
Diabetes	DIABETES	1	Diabetic
		2	Diabetic (controlled)
		3	Not diabetic
Height	HEIGHT		Enter height in inches with shoes (without shoes: add 1 inch for males, 2 inches for females).
Weight	WEIGHT		Enter weight in pounds (in indoor clothing and shoes).

* Number of "drinks" should include aperitifs, wines, beer, etc.

APPENDIX—*Continued*

Factor	Abbreviation	Code	Description
Frame	FRAME	1	Small
		2	Medium
		3	Large
Drugs and medication influencing motor vehicle operation	DRUGS/MED	1	Excess
		2	Moderate
		3	None
Exercise	EXERCISE	1	Sedentary: work and leisure; under 5 flights of stairs or half-mile walking per day
		2	Low moderate: some activity, work and leisure; between 5 and 15 flights of stairs or 0.5 to 1.5 miles walking or comparable daily activity
		3	High moderate: programmed exercise 4 times per week or 1.5 to 2 miles of walking or 15 to 20 flights of stairs or comparable daily activity
		4	Vigorous: greater than moderate
Smoking habits: (1) for current smoker, heaviest amount smoked in past 5 years; (2) for ex-smoker, heaviest amount smoked in year before quitting	SMOKING	1	Cigarettes, 40 or more/day
		2	Cigarettes, 20–39/day
		3	Cigarettes, 10–19/day
		4	Cigarettes, less than 10/day
		5	Cigars or pipes only; 5 or more/day or any amount inhaled
		6	Cigars or pipes only; less than 5/day *not* inhaled
		7	Nonsmoker (never smoked or not smoked for 10 years)
Current smoking status	STOPSMOK	0	Still smoking or nonsmoker
		1	Years of having stopped smoking
		2	
		3	
		4	
		5	
		6	
		7	
		8	
		9	
Family history of ischemic heart disease	FH/HEART	1	Both parents died before 60 of ischemic heart disease.
		2	One parent died before 60 of ischemic heart disease.
		3	One or both parents died before 60 of cause other than ischemic heart disease or both are still alive and below age 60.
		4	None of the above
Family history of diabetes (mother, father, sister, brother, child)	FH/DIAB	1	Yes
		2	No
Family history of suicide	FH/SUICD	1	Yes
		2	No
Emphysema and/or bronchitis	EMPHYSEMA	1	Has emphysema and/or bronchitis
		2	Has no signs or symptoms of emphysema and/or bronchitis

APPENDIX—*Continued*

Factor	Abbreviation	Code	Description
Rectal polyp	POLYP	1	Has had
		2	Has not had
Proctosigmoidoscopy	PROCTO	1	Has annually
		2	Does not have annually
Rectal bleeding	RCTBLOOD	1	Has had undiagnosed rectal bleeding in the past year
		2	Has not had undiagnosed rectal bleeding in the past year
Chronic rheumatic heart disease	RH: FEVER	1	Rheumatic heart murmur, no chemoprophylaxis
		2	Rheumatic heart murmur, on chemoprophylaxis
		3	History of rheumatic fever but no murmur, no chemoprophylaxis
		4	History of rheumatic fever but no heart murmur, on chemoprophylaxis
		5	No history of rheumatic fever and no rheumatic heart murmur
Signs or symptoms of chronic rheumatic heart disease	RH: S/O/S	1	No
		2	Yes
Ulcerative colitis	ULCERCOL	1	Has had ulcerative colitis 10 years or more
		2	Has had ulcerative colitis less than 10 years
		3	Has no symptoms of ulcerative colitis
The following factors are to be coded for females only:			
Vaginal bleeding	VAGBLOOD	1	Has had undiagnosed vaginal bleeding in past year
		2	Has not had undiagnosed vaginal bleeding in past year
Age at marriage or onset of intercourse	AGE/MAR	1	Teenage
		2	20–25
		3	Over 25 or never
Pap smear	PAPSMEAR	1	Has not had
		2	Negative within 5 years
		3	Negative within 1 year
		4	3 negative within 5 years
Economic and social status	SOCIO/EC	1	Low
		2	Average
		3	High
Jewish	JEWISH	1	No
		2	Yes
Family history of breast cancer	FH/BREAST	1	Mother or sister had breast cancer.
		2	Mother or sister had breast cancer but patient examines breasts regularly and has periodic examination by physician.
		3	Neither mother nor sister had breast cancer.
		4	Neither had breast cancer but patient examines breasts regularly and has periodic examination by physician.

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DISCUSSION OF PRECEDING PAPER

STEVEN HABERMAN:

The paper introduces some of the recent developments in statistical methodology that are applicable to life insurance underwriting.

Discriminant analysis is used to develop an automatic procedure for identifying those applications that are most likely to be accepted on a substandard basis or rejected. The concept of biological age is introduced but not fully developed. Thus, Table 2 in the paper assigns biological ages on the basis of serum cholesterol, systolic blood pressure, smoking status, and the comparative risk of developing cardiovascular disease relative to an average person. The concept of biological age is most useful in life assurance underwriting when the endpoint under consideration is death rather than the development of a particular disease.

The authors have not discussed models for assessing the absolute and relative survivorship (and hence mortality) of standard and substandard lives. It is here that considerable advances in methodology have appeared in the statistical literature, extending the multiple decrement table [1-3]. It is now possible to relate survival to a set of covariates measured at the time of an individual's application, through an adaptation of regression [1-2]. This sort of technique would lead to the identification of factors or sets of factors that significantly shorten or lengthen survival for standard and substandard lives. Hence, an individual's profile could be transformed into a measure of biological age as the authors suggest in their paper.

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JOHN WEST HADLEY:

I was fascinated by the authors' attempts to reproduce human underwriting via the computer. This idea has had great appeal for me, although my concept essentially had been to program the medical underwriting manual and similar

decision procedures regarding aviation, avocations, and other insurance in force and so forth. All information on the application would be keyed into the computer, which would indicate the appropriate underwriting action. Naturally a great many applications would involve either gray areas for which the manual provides no clear cut action (such as relatively new medical techniques), or combinations of various conditions too complex to program effectively. In such situations, the computer simply would reject the case as one requiring evaluation by an underwriter. In this way the computer could handle the simpler cases, freeing the underwriter for the more difficult ones. This also would ensure more consistent underwriting, and possibly increase the underwriter's job satisfaction by reducing the "rubber stamping" content of his work. Underwriters could spend more time researching new developments in medicine to refine the underwriting process. Computer underwriting could be used to experiment with various underwriting guidelines without confusing those doing the underwriting. The computer also could serve as a training tool by providing a quick check on how well the underwriter is doing.

I would like to know if the authors examined the approach I've described and whether or not they consider it feasible. Admittedly, the initial job of establishing the program would be mammoth, but even that would not be without its benefits. Almost certainly, it would generate a great deal of consideration of the manner in which various conditions interrelate and how best to treat them in the underwriting process.

Advances in medicine provide a possible pitfall in the practical application of the model. The user would need to monitor changing underwriting practices carefully and test the validity of the model periodically. Not just the weightings but also the variables entering the model likely would change over time. Factoring experience back into the model will help, but it also is important to reflect factors not previously available or without previous significant impact, but considered likely to affect future experience.

I suspect most insurers will be very slow to accept this model as a viable alternative, despite the demonstrable cost savings. I would be interested to know how it was accepted at Mutual Life Assurance, particularly by the underwriters, and how extensively they have used it since this work.

How effectively might the procedure be applied to individual health insurance, either disability income or major medical? One problem is that the percentage of policies not issued as applied for (including declinations, rated issues, and standard issues with exclusion riders) is much greater than for life insurance. If the computer were used only to provide definite issue

decisions, with the underwriters reviewing the rest, how long might it take to recover the initial investment?

I believe there was a minor flaw in the cost justification. The cases rated standard by the computer likely are the easier ones to underwrite, and those generating fewer medical requirements, so that the average cost to underwrite the remaining cases should be larger than the overall average. This increase in unit cost, plus the relatively insignificant computer cost, times the number of cases "humanly" underwritten, should be deducted from the cost savings on the computer-underwritten cases.

I thank the authors for an enlightening paper.

(AUTHORS' REVIEW OF DISCUSSION)

ROBERT L. BROWN AND K.S. BROWN:

We thank Mr. Hadley and Dr. Haberman for their thoughtful comments on our paper. As indicated in the paper, our original interest was to investigate whether existing "biological age" models could be used in the underwriting process. Unfortunately, there was little correspondence between the variables input to these biological age models and those appearing on the application form. Thus, we adopted the approach outlined in the paper. We agree that programming the underwriting manual would be a mammoth task, and we initially did not consider that approach for that reason. Our aim was to determine whether we could duplicate the ratings of underwriters using this simpler model, which does isolate those variables that seem to be important in underwriting the given set of applications. To this end we were reasonably successful.

Advances in medicine pose problems to any model that seeks to predict future claims, including a standard approach to underwriting. We agree that any model would need to be monitored closely, and would argue that this is one advantage of computerizing the entire process; namely that claims information can be combined with information obtained from the application to update and refine the model continually.

Dr. Haberman refers to recent advances in statistical methodology that permit survival to be related to a set of covariates. We are extremely interested in applications of this methodology but lack the raw data on which to investigate the potential applications to the underwriting process. Again, a computerized system would enable the data to be collected routinely.

Mr. Hadley's comments concerning cost comparisons are well taken. However, the computer still can serve as a useful screening device, underwriting the straightforward cases, and possibly routing the more complicated

cases to the underwriter best able to do the underwriting of the application. Further, in the case of the Mutual Life data, approximately 10 percent of the applications were absolutely clear (no "yes" answers). Obviously there should be no need for human underwriting of these applications.

Mr. Hadley mentions one useful spinoff advantage of having a computerized underwriting system, namely, being able to use it to train new underwriters. It also can be used to check the consistency of the present underwriters by giving them the same applicant profile and determining if they all make the same decision every time.

Mr. Hadley asks how the new system was accepted at Mutual Life. To date, our ideas have not been adopted at Mutual Life. We understand that this project has relatively high priority but the systems people are occupied with other problems at the moment. Nevertheless, we do not foresee widespread adoption of the methodology, although we feel it is sound and has obvious cost-saving potential.

Finally, we cannot offer any comments on the applicability of our ideas to health insurance since we are not experts in this area. We feel that morbidity would be much more difficult to handle than mortality.

Again, sincere thanks to the two discussants for their stimulating remarks.