Volume 4, Number 1, 2007, pp. 39-60

Application of nonlinear models to studies in the ergonomics area

Luiz Bueno da Silva
Federal University of Paraíba - UFPB
João Pessoa, PB, Brazil
E-mail: bueno@ct.ufpb.br

Anand Subramanian
Federal University of Paraíba - UFPB
João Pessoa, PB, Brazil
E-mail: anandsubraman@gmail.com

Francisco Soares Másculo
Federal University of Paraíba - UFPB
João Pessoa, PB, Brazil
E-mail: masculo@ct.ufpb.br

Fernanda Diniz de Sá
Federal University of Paraíba - UFPB
João Pessoa, PB, Brazil
E-mail: fediniz@yahoo.com.br

Abstract

This paper presents nonlinear models applied to studies in the ergonomics area. In general, these models evaluate the nature of the relationship between a group of Independent Variables (IVs) and one Dependent Variable (DV). In this study the interest is on the effect of the variables thermal perception (P_t); noise perception (P_n); age (A); time of service (T_s) on the working ability. The sample was constituted of 60 public bus drivers. The Chi-Square test was used to verify the significance between the final models and the intercept, thus analyzing the relationship between the dependent and independent variables. The Wald's test was applied in order to evaluate the consistency of the parameter estimates of the IVs. A logistic regression model was built including the variables P_t , P_n and A as the IVs. Since A has a greater influence on the working ability of the driver, another logistic regression model was constructed considering just this variable as the IV. It was concluded that when the bus driver's age increases by one unit, there is a 23.5% chance of his work ability to fall in the range of poor to moderate.

Keywords: Nonlinear estimation, logistics regression, work ability, perception, age.

1. INTRODUCTION

In the most general terms, the nonlinear estimation will compute the nature of the relationship between a set of Independent Variables (IVs) and one Dependent Variable (DV); it may be said that it is a generalization of the multiple regression methods called ANOVA and MANOVA; it essentially specifies some kind of continuity or discontinuity in the regression model. Thus, the DV can be specified to be a logarithmic function of the IV(s) an exponential function.

When allowing for any type of relationship between the IVs and the DV, two issues arise. First, what types of relationships make sense, i.e., are interpretable in a meaningful manner? A simple linear relationship is very convenient since it allows one to make straightforward interpretations. Nonlinear relationships cannot usually be interpreted and verbalized in such a simple manner. The second issue is how to exactly compute the relationship, that is, how to arrive at results that allow one to say whether or not there is a nonlinear relationship as predicted.

Some studies may generate data whose outcome for each individual is a binary, i.e., it may be represented only by two values, generally 0 or 1. There are, at least, four functions used in the data modeling whose variable is binary: logit, probit, complimentary log-log function and log-log function. In the field of the experimental human sciences and ergonomics, the logistics function has been very much used, not only because its theoretical functions are simpler, but, mainly, because of its simple interpretation as a logarithm of the chance rate (odds ratio). In the use of the logistics regression model, one might be interested in the effect of a specific risk factor or in the identification of various associated factors with the DV.

Traditionally, the studies involving a worker population search for reasonable associations between pathologies and probable risks factors (Cordeiro, 1991). In this way, it is notable the production of essays which study associations between the general decrease in the workers performance and the occupational exposure to environments with high thermal and noise levels. One of the main causes for this interest is determined by the effects of this exposure like the decrease in the alert state, and also the risk of enchaining some other health disturbances for these people (Cordeiro *et al.,* 2005, Fleig, 2004; Rodrigues and Magalhães, 2004; Pimentel-Souza, 2000).

Recent researches demonstrate activities related to transportation as one of high risk for physical and mental health of the worker, due to the occupational exposure factors, e.g. noise and thermal (Karazman *et al.*, 2000, Kloimueller *et al.*, 2000, Mello, 2000, Costa, 2003, Fleig, 2004).

In this work, we apply nonlinear estimation, namely the Logistic Regression to evaluate the effect of the environmental conditions, age and time of service on the working capacity of urban public bus drivers.

This paper is organized as follows. Section 2 presents a brief literature review of some works that had used logistic regression in the ergonomics area. Section 3 deals with the nonlinear estimation, emphasizing the main aspects of the Logistic Regression. Section 4 illustrates the Methodology used in this research. Section 5 contains the results obtained followed by some discussions. Section 6 presents some final considerations and concluding remarks

2. LITERATURE REVIEW

Several studies have applied nonlinear statistical techniques such as logistic regression to analyze ergonomics data.

Werner *et al.* (2005) in their work titled "Predictors of Upper Extremity Discomfort: A Longitudinal Study of Industrial and Clerical Workers" studied a cohort of 501 active workers. Cases were defined as workers who were asymptomatic or had a low discomfort score of 1 or 2 at baseline testing and went on to report a discomfort score of 4 or above on a 10-point visual analog scale. This change was considered clinically significant. Controls had a low baseline discomfort score and continued to have a low discomfort rating throughout the study. The risk factors found to have the highest predictive value for identifying a person who is likely to develop a significant upper extremity discomfort rating included age over 40, a Body Mass Index (BMI) over 28, a complaint of baseline discomfort, the severity of the baseline discomfort rating and a job that had a high hand activity level (based upon hand repetition and force). The risk profile identified both ergonomic and personal health factors as risks and both factors may be amenable to prevention strategies.

Murphy *et al.* (2007) did a cross-sectional study about back and neck pain among English schoolchildren and associated physical and psychological risk factors. They set out to identify the associations between ergonomics and other factors with back and neck pain. Self-reported questionnaires were used to record health outcomes and potential risk factors in state schools. Six hundred and seventy-nine schoolchildren from Surrey in the United Kingdom aged 11–14 years took part. Twenty-seven percent of children reported having neck pain, 18% reported having upper back pain, and 22% reported having low back pain. A forward stepwise logistic regression was performed with pain categories the dependent variables. Neck pain was significantly associated with school furniture features, emotional and conduct problems, family history of low back pain and previous treatment for musculoskeletal disorders. Upper back pain was associated with school bag weight (3.4 – 4.45 kg), school furniture features, emotional problems and previous treatment for musculoskeletal disorders. Low back pain was associated with school furniture features, emotional problems, family history and previous injury or accident. It is important to recognize the influence of physical, psychological and family factors in children's pain.

Zetterberg *et al.* (1997) studied 564 car assembly workers, 440 men and 124 women. Questionnaires, including work satisfaction, orthopaedic examination and exposure evaluation were performed. Women had more neck-myalgia and more physical signs from the hands, especially nerve related problems and tendinitis as compared to men. Impingement of the shoulder was equally prevalent among women and men, doing the same work. Women showed a higher work satisfaction than men. Stress at work correlated both to subjective complaints from all locations in the upper half of the body and to findings at the physical examination. A logistic regression analysis showed that subjective complaints from the neck, shoulders and feet correlated to less good work satisfaction, while work dissatisfaction was not correlated to any of the physical signs. Those having station-bound work showed less good relations to foremen/workmates and better to the work in comparison with the workstations at the assembly line.

Fogleman and Lewis (2002) studied factors associated with self-reported musculoskeletal discomfort in Video Display Terminal (VDT) users. The data were collected via a survey administered to 373 persons who use a VDT at a corporate office site; 292 of the surveys were returned (78%). Respondents were asked to report on symptoms for six body regions, as well as job requirement information, demographic information, and a question regarding non-occupational hobbies. The body regions included were: head and eyes, neck and upper back, lower back, shoulders, elbows and forearms, and hands and wrists. Descriptive information on these data was obtained through exploratory factor analysis, while logistic regression was used to estimate risk. The results indicated a statistically significant increased risk of discomfort on each of the body regions as the number of hours of keyboard use increases. Improper monitor and keyboard position were also significantly associated with head/eye and shoulder/back discomfort, respectively. These results emphasized the importance of workstation ergonomics and the need to limit the number of uninterrupted hours at the keyboard to reduce musculoskeletal symptoms.

Shipp *et al.* (2007) dealt with a study titled "Severe Back Pain Among Farmworker High School Students From Starr County, Texas: Baseline Results". This cohort study was among the first to estimate the prevalence of and examine potential risk factors for severe back pain (resulting in medical care, 4+ hours of time lost, or pain lasting 1+ weeks) among adolescent farm workers. These youth often performed tasks requiring bent/stooped postures and heavy lifting. Of 2536 students who participated (response rate across the three public high schools, 61.2% to 83.9%), 410 students were farm workers. Students completed a self-administered Web-based survey including farm work/nonfarm work and back-pain items relating to a 9-month period. The prevalence of severe back pain was 15.7% among farm workers and 12.4% among nonworkers. The prevalence increased to 19.1% among farm workers who also did nonfarm work. A multiple logistic regression for farm workers showed that significantly increased adjusted odds ratios for severe back pain were female sex (4.59); prior accident/back injury (9.04); feeling tense, stressed, or anxious sometimes/often (4.11); lifting/carrying heavy objects not at work (2.98); current tobacco use (2.79); 6+ years involved in migrant farm work (5.02); working with/around knives (3.87); and working on corn crops (3.40). Areas for further research included ergonomic exposure assessments and examining the effects of doing farm work and non-farm work simultaneously.

Feuerstein (2003) did a study of clinical and workplace factors associated with a return to modified duty in work-related upper extremity disorders. Return to work following treatment for a Work-Related Upper Extremity Disorder (WRUED) is affected by a variety of medical, workplace, and personal factors and returning to modified duty may ease the transition to normal work activities. This study surveyed 165 federal government employees (127 females, 38 males) who were unable to resume their normal work after filing a workers' compensation claim for a WRUED (<90 days from claim filing) and who volunteered for a randomized study of alternative case management strategies. Before randomization, participants completed a baseline survey of upper extremity (UE) symptoms, functional limitations, and workplace factors. At baseline, 58 participants (35%) were working modified duty and 107 participants (65%) were not working. Compared with participants working modified duty, those who were not working were more likely to report: (a) a diagnosis of mononeuropathy, Odds Ratio (OR) = 3.16 (95% Confidence Interval (CI) = 1.37 – 7.14) versus enthesopathy, (b) higher pain ratings, OR = 1.43 (95% CI = 1.01 – 2.01), (c) greater functional limitations, OR = 1.63 (95% CI = 1.11–2.38), and (d) higher level of ergonomic stressors, OR = 1.62 (95% CI = 1.09 – 2.43) in a multivariable logistic regression. Measures of high risk work styles (fast pace and working despite pain) were associated with greater perceptions of ergonomic exposure, but not with work status. The model had 87.9% sensitivity and 43.1% specificity to correctly classify those not working (overall classification 72.1% correct). The results suggested that modified duty for workers with persistent WRUEDs may be enhanced by assessing perceived functional limitation and ergonomic exposure as well as the type and severity of symptoms.

Sampaio *et al.* (2006) realized a study very similar titled "Work Ability and Stress in a Bus Transportation Company". Demographic, occupational and psychosocial characteristics affected the health and occupational performance of workers. The objective of the study was to elaborate a profile of the work ability and factors affecting it in a bus transportation company in Belo Horizonte, Brazil. The instruments used included a socio-demographic and occupational questionnaire, the Work Ability Index and the Job Stress Scale. Demographic information revealed that 85.7% of the 126 employees of the company were active workers, 98% were males with an average of 39 years of age (SD = 10) and 79 months at the company (SD = 68) and more than half reported had a low level of schooling. In terms of personal habits, 88% were exposed to one or more risk factors, especially a sedentary lifestyle. The average strain value (as a consequence of stress) was 0.78 (SD = 0.2) and 75.3% reported episodes of violence at the workplace. The work ability was good to excellent among 89% of the workers. Results from the logistic regression analysis showed that strain was the only significant variable related to Work Ability Index, (estimated odds ratio of 0.02). The results suggested that psychosocial factors presented the greatest association with work ability, and preventative and/or corrective measures should be implemented.

3. NONLINEAR ESTIMATION

The nonlinear estimation is a general fitting procedure that will estimate any kind of relationship between a DV, and a list of IVs. In general, all regression models may be stated as:

$$y = F(x_1, x_2, ..., x_j) \quad (1)$$

In most general terms, the user is interested in whether and how a DV is related to a list of IVs. An example would be the linear multiple regression model. Hence:

$$y = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + ... + \beta_p \cdot x_p + \varepsilon \quad (2)$$

where $x_1, x_2, ..., x_p$ are constants, $\beta_0, \beta_1, \beta_2, ..., \beta_p$ are parameters denominated as partial regression coefficients and ε the residues. However, the multiple regression does not "know" that the response variable is binary in *nature*. Therefore, it will inevitably fit a model that leads to predicted values that are greater than 1 or less than 0. However, since these values are not valid the restriction in the range of the binary variable (between 0 and 1) is ignored if one uses standard multiple regression.

3.1 Logistic Regression Model (LRM)

According to Hosmer and Lemeshow (1989) and Casella and Berger (2002), the name logit stems from the fact that one can easily linearize this model via logit transformation. Suppose the quantity $\pi(x) = E(Y|x) = \beta_0 + \beta_1 x$ (this means it may be expressed as an eq. linear in x) represent the conditional mean of Y given x when the logistic distribution is used. The specific form of the logistic regression model used in this paper is shown in eq. (3).

$$\pi(x) = \frac{e^{\beta_0+\beta_1 x}}{1+e^{\beta_0+\beta_1 x}} \qquad (3)$$

The logit transformation used in logistic regression is defined, in terms of $\varpi(x)$, as follows:

$$g(x) = \ln\left[\frac{\pi(x)}{1-\pi(x)}\right] = \beta_0 + \beta_1 x \qquad (4)$$

The importance of this transformation is that $g(x)$ has many of the desirable properties of linear regression model. The logit, $g(x)$ is linear in its parameters, may be continuous, and may range from $-\infty$ to $+\infty$, depending on the range of x.

In addition, as in the case of linear regression, the strength of a modeling technique lies in its ability to model many variables, some of which may be on different measurement scales.

Consider a collection of p independent variables which will be denoted by the vector $x' = (x_{1,} x_2, \ldots, x_p)$. For the moment it will be assumed that each of these variables is least-interval scaled. Let the conditional probability presented by the outcome be denoted by $P(Y = 1|x) = \pi(x)$. Then the logit of the multiple logistic regression model is given by the eq. (5).

$$g(x) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p = \beta_0 + \sum_{i=1}^{p} \beta_i x_i \qquad (5)$$

where $\pi(x) = \dfrac{e^{g(x)}}{1+e^{g(x)}}$ (6)

If some of the IVs are discrete and nominal-scaled, e.g., race, sex, perception about environmental conditions, treatment group, and so forth, then it is inappropriate to include them in the model as if they were interval scaled. This is because the numbers used to represent the various levels are merely identifiers, and have no numeric significance. In this situation, the method of choice is to use a collection of design variables (or dummy variables).

After estimating the coefficients, a first look at the fitted model commonly concerns an assessment of the significance of the variables in the model. This usually involves formulation and testing of a statistical hypothesis to determine whether the IVs in the model are "significantly" related to the outcome variable. The method for performing this test is quite general and differs from one type of model to the next only in the specific details.

Two statistical tests have been suggested: Wald's and Score. The Wald's test compares the maximum likelihood estimate of the slope parameter, $\hat{\beta}_1$, to an estimate of its Standard Error (SE). The resulting ratio, under the hypothesis that $\beta_1 = 0$, follows a standard normal distribution. Before concluding that any or all of the coefficients are nonzero, it is necessary to apply the univariate Wald's test statistics:

$$W_j = \frac{\hat{\beta}_j}{SE(\hat{\beta}_j)} \quad (7)$$

The use of the Score test is limited by the fact that it cannot be obtained easily from some software packages. It's based on the distribution theory of the derivatives of the log likelihood. However, this test does not require costly computational task. Proponents of the Score test cite this reduced computational effort as its major advantage.

Two other methods may also be be used for estimating the coefficients: (i) noniterative weighted least squares, and (ii) discriminant function analysis. Grizzle *et al.* (1969) *apud* Hosmer and Lemeshow (1989) demonstrate that the logistic regression model is an example of a very general class of models that can be handled by their methods, that is, by using only one iteration in the process.

3.2 Interpretation of the LRM coefficients

The estimated coefficients for the independent variables represent the slope of a function of the DV in the IV. Thus, interpretation involves two issues: determining the functional relationship between the dependent and independent variables, and appropriately defining the unit of change for the IV.

In the LRM the link function is the logit transformation presented in eq. (4). For this model we recall that the slope coefficient, β_1, is equal to the difference between the value of the DV at $x + 1$ and the value of the DV at x, for any value of x, that is:

$$\beta_1 = g(x+1) - g(x) \quad (8)$$

In other words, the slope coefficient represents the change in the logit for a change of one unit in the IV x.

Consider a situation where the DV is dichotomous, i.e., x is coded as either 0 or 1. Under this model there are two values of $\pi(x)$ and two equivalent values of $1 - \pi(x)$. These values may be conveniently displayed as shown in Table 1.

Table 1:Values of the logistic regression model when the DV is dichotomous

Outcome (Y) \ Independent (X)	X = 1	X = 0
Y = 1	$\pi(1)=\frac{e^{\beta_0+\beta_1}}{1+e^{\beta_0+\beta_1}}$	$\pi(0)=\frac{e^{\beta_0}}{1+e^{\beta_0}}$
Y = 0	$1-\pi(1)=\frac{1}{1+e^{\beta_0+\beta_1}}$	$1-\pi(0)=\frac{1}{1+e^{\beta_0}}$
Total	1.0	1.0

The odds of the outcome being present among individuals with $x = 1$ is defined as $\frac{\pi(1)}{[1-\pi(1)]}$. Similarly, the odds of the outcome being present among individuals with $x = 0$ is defined as $\frac{\pi(0)}{[1-\pi(0)]}$. The log of the odds, as defined previously, is called the logit and, in this case, these are:

$$g(1) = \ln\left\{\frac{\pi(1)}{[1-\pi(1)]}\right\} \qquad (9)$$

and

$$g(0) = \ln\left\{\frac{\pi(0)}{[1-\pi(0)]}\right\} \qquad (10)$$

The odds ratio, denoted by ψ, is defined as the ratio of the odds for $x = 1$ to the odds for $x = 0$, and is given by the eq. (11).

$$\psi = \frac{\dfrac{\pi(1)}{[1-\pi(1)]}}{\dfrac{\pi(0)}{[1-\pi(0)]}} \qquad (11)$$

Volume 4, Number 1, 2007, pp. 39-60

The log of the odds ratio, termed log-odds ratio, or log-odds, is:

$$\ln(\psi) = \ln\left[\frac{\dfrac{\pi(1)}{[1-\pi(1)]}}{\dfrac{\pi(0)}{[1-\pi(0)]}}\right] = g(1) - g(0) \qquad (12)$$

Using the expressions for the logistic regression model shown in Table 1 and eq. 11 the odds ratio is:

$$\psi = \frac{\left(\dfrac{e^{\beta_0+\beta_1}}{1+e^{\beta_0+\beta_1}}\right)\left(1+e^{\beta_0+\beta_1}\right)}{\left(\dfrac{e^{\beta_0}}{1+e^{\beta_0}}\right)\left(1+e^{\beta_0}\right)} = \frac{e^{\beta_0+\beta_1}}{e^{\beta_0}} = e^{\beta_1} \Rightarrow \psi = e^{\beta_1} \qquad (13)$$

and the logit difference, or log odds, is

$$\ln(\psi) = \ln(e^{\beta_1}) = \beta_1 \qquad (14)$$

This fact concerning the interpretability of the coefficients is the fundamental reason why logistic regression has proven such a powerful analytical tool for epidemiology, health and ergonomics areas and it can also be applied in the field of production engineering.

The odds is a measure of association and has found wide use, as it approximates how much more likely (or unlikely) it is for the outcome to be present among those with x = 1 than between those with x = 0. (Breslow and Day, 1980, Schlesselman, 1982, Kelsey *et al.*, 1986, Rothman, 1986).

The interpretation given for the odds ratio is based on the fact that in many instances it approximates a quantity called the relative risk. This parameter can be represented by η and is equal to the ratio $\frac{\pi(1)}{\pi(0)}$. It follows from eq. (10) that $\psi \approx \eta$ if $\frac{[1-\pi(0)]}{[1-\pi(1)]} \approx 1$. This approximation will hold when $\pi(x)$ is small for both x = 1 and 0.

4. METHODOLOGY

The population in this study consisted of 60 bus drivers, male, ages between 24 and 57 years, working in one of the six urban public transportation concessionaries in the city of João Pessoa, Brazil for at least four years in this function. Due to the ethical considerations regarding such studies, the company involved did not permit their identification.

To evaluate the work ability, use was made of an auto-applicable questionnaire named Work Ability Index – WAI (Tuomi *et al.*, 1997), utilized for workers' health service. The work ability refers to the worker's capability in performing his duties and is graded according to the points system shown in Table 2. Along with the WAI, another questionnaire was applied, regarding aspects related to the bus drivers' perception to the thermal and noisy environment, to the work organization and to the population socio-demographic data.

Table 2: Work ability index classification

Points	Work Ability
7-27	Poor
28-36	Moderate
37-43	Good
44-49	Excellent

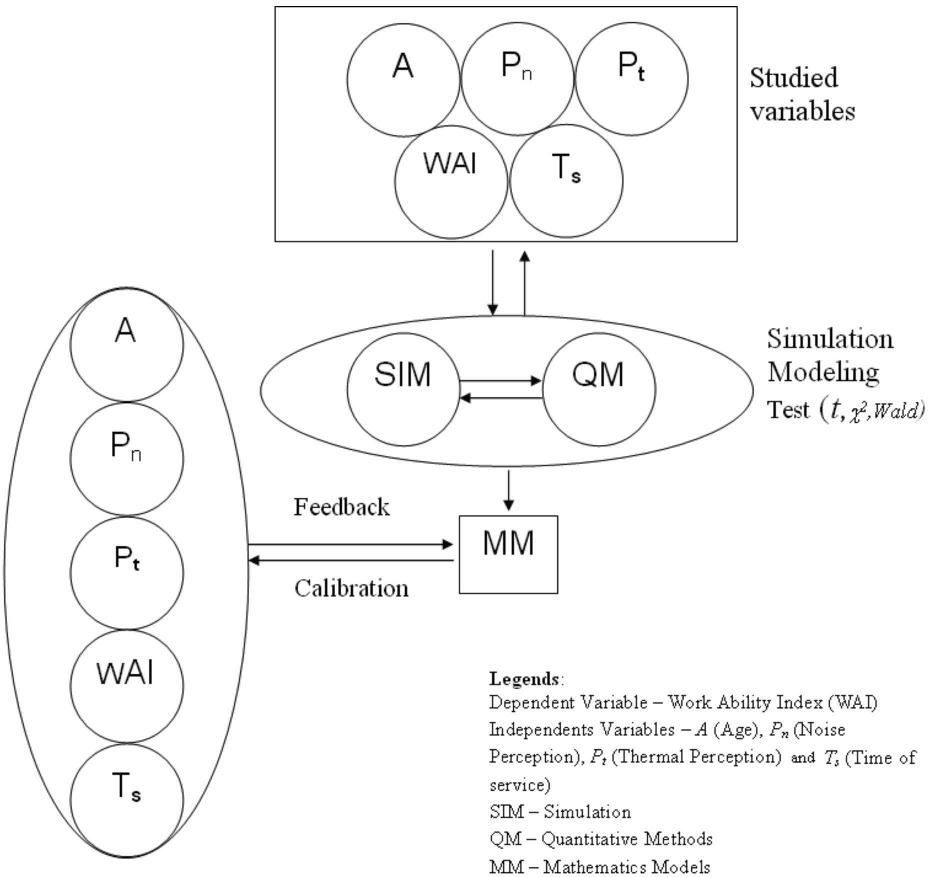

Figure 1: Methodology employed

A non-linear estimating logistic regression was applied in order to verify the relations between the independent variables (age (A), time of service as an urban bus driver (T_s) and perceptions about the thermal (P_t) and noise (P_n) environment and the dependent variable (WAI). The perception variables P_n and P_t were classified as: bad (1), regular (2), good (3) and excellent (4). The steps of the statistical analysis are shown in Fig. 1.

The DV Y was transformed into a dummy variable for the logistics regression analysis. The cutoff point stipulated for Y was: $36 < \text{WAI} \leq 49$, $Y = 0$ and $7 \leq \text{WAI} \leq 36$, $Y = 1$.

With an aim to evaluate the significance and consistence of the logistic regression models, the Chi-Square test and Wald's test were applied. The first is related to the model fitting information and likelihood ratio tests while the second is associated to the parameter estimates.

The softwares SPSS and STATISTICA were used as an experimental instrument for this research.

5. RESULTS

The sample's WAI varied from a minimum score of 28 minimum score to a maximum of 48. The WAI distributions for age and time of service are presented in Table 3.

Table 3: Work ability distribution for age and time of service categories.

Variable Category		*WAI*									
		Excellent		Good		Moderate		Poor		Total	
		n°	%	n°	%	n°	%	n°	%	n°	%
Age	24--| 34	7	11.6	5	8.3	1	1.6	0	0	13	1.6
	35--| 44	7	11.6	3	5	3	5	0	0	13	21.6
	45 or more	7	11.6	3	5	24	40	0	0	34	56.6
	Total	21	35	11	18.3	28	46.6	0	0	60	100
Time of service	4 ---| 10	14	23.3	7	11.6	3	5	0	0	24	40
	11---| 17	1	1.6	0	0	7	11.6	0	0	8	3.3
	18 or more	6	10	4	6.6	18	30	0	0	28	6.6
	Total	21	35	11	18.3	28	46.6	0	0	60	100

The results relating to perception that the bus drivers have about heat and noise of their work environment are shown in Table 4.

Table 4: Bus driver perception about the noisy and thermal environment.

NOISE		HEAT	
Answer	**%**	**Answer**	**%**
Poor	35	Poor	38.3
Moderate	35	Moderate	35
Good	30	Good	26.6
Excellent	0	Excellent	0
Total	100	Total	100

The statistical analysis showed that the set of Independent Variables (IVs), that is, Thermal Perception (P_t), Noise Perception (P_n), Time of Service (T_s) and Age (A), together, has a relation with the DV, as recorded in Table 5. This statement is pertinent since the Chi-square value for the difference between the final and the intercept models is highly significant.

Table 5: Model Fitting Information (Pt, Pn, Ts and A as independent variables)

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	82.108			
Final	44.913	37.195	4	0.000

Table 6: Likelihood Ratio Tests (Pt, Pn, Ts and A as independent variables)

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	51.105	6.192	1	0.013
P_t	49.848	4.935	1	0.026
P_n	50.590	5.677	1	0.017
T_s	44.915	0.002	1	0.968
A	56.107	11.194	1	0.001

On the other hand, as shown in Table 6, the Chi-square values of P_t, P_n and A are significant while the same is not true with the variable T_s ($Sig.$ = 0.968 > α = 0.05). This shows a probable relationship between such variables and the WAI.

This affirmation can be confirmed by Wald's test. Analyzing the consistence of the parameters of the logistic regression model, presented in Table 7, it can be verified that only the variable T_s is not consistent ($Sig = 0.968 > 0.05 = \alpha$). A correlation analysis was done involving T_s and each one of the remaining variables and it was observed that the Pearson's correlation coefficient (R) between T_s and A was 0.759. This value demonstrates a reasonable linear correlation between these variables and it might be a possible explanation for the inconsistency of T_s in the current model. Therefore, only the variables P_t, P_n and A should be considered, requiring a re-evaluation of the relation between these variables and the WAI.

Table 7: Parameter Estimates (Pt, Pn, Ts and A as independent variables)

	B	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
							Lower Bound	Upper Bound
Intercept	-6.150	2.885	4.543	1	0.033			
P_t	-1.046	0.497	4.432	1	0.035	0.351	0.133	0.930
P_n	-1.029	0.460	5.006	1	0.025	0.357	0.145	0.880
T_s	-0.003	0.067	0.002	1	0.968	0.997	0.875	1.137
A	0.221	0.077	8.184	1	0.004	1.247	0.221	0.077

However, in spite of the inconsistency of the variable T_s, Table 8 shows that all independent variables, jointly, have correctly classified the WAI in 85.0% of the cases. The 15.0% inappropriate classifications might be related to unevaluated variables, to the questionnaire elaboration, or even due to the subjective perception of each bus driver.

Since the variable T_s appears to be inconsistent, it was removed from the analysis, and the relation between the variables P_t, P_n, A and the dependent variable WAI was re-evaluated. Thus, from Table 9, it can be observed that difference between the final and intercept models is significantly high ($Sig. = 0.000 < \alpha = 0.05$). This would strongly indicate that these three variables have a considerable influence on the WAI.

Table 8: Classifications of the variable WAI (Pt, Pn, Ts and A as independent variables)

Observed	Predicted		
	0.00	1,00	Percent Correct
0.00	22	4	84.6%
1.00	5	29	85.3%
Overall Percentage	45.0%	55.0%	85.0%

Table 9: Model Fitting Information (Pt, Pn and A as independent variables)

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	75.176			
Final	37.983	37.193	3	0.000

Table 10: Likelihood Ratio Tests (Pt, Pn and A as independent variables)

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	44.741	6.758	1	0.009
P_t	42.984	5.001	1	0.025
P_n	43.683	5.700	1	0.017
A	61.091	23.108	1	0.000

Table 11: Parameter Estimates (Pt, Pn and A as independent variables)

	B	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
							Lower Bound	Upper Bound
Intercept	-6.125	2.818	4.724	1	0.030			
P_t	-1.043	0.493	4.478	1	0.034	0.352	0.134	0.926
P_n	-1.027	0.458	5.027	1	0.025	0.358	0.146	0.879
A	0.219	0.064	11.651	1	0.001	1.245	1.098	1.411

Table 10 shows that there is a strong relationship between each independent variable and the WAI, with A being the most significant. This statement is ratified throughout the Wald's statistic as observed in Table 11.

After removing the variable T_s, the percentage of correct classifications (Table 12) has increased to 86.7%, a higher value if compared to the previous model (see Table 8).

Volume 4, Number 1, 2007, pp. 39-60

Table 12: Classification of the WAI variable percentage (Pt, Pn and A as independent variables)

Observed	Predicted		
	0.00	1.00	Percent Correct
0.00	23	3	88.5%
1.00	5	29	85.3%
Overall Percentage	46.7%	53.3%	86.7%

From the data found in Table 11, the multiple logistic regression model, with P_t, P_n, A as the IVs, can be expressed as follows:

$$Y = \frac{\exp(-6.125 - 1.043 \cdot P_t - 1.027 \cdot P_n + 0.219 \cdot A)}{1 + \exp(-6.125 - 1.043 \cdot P_t - 1.027 \cdot P_n + 0.219 \cdot A)} \qquad (15)$$

Finally, a simple logistic regression analysis was conducted considering only A as the IV because it tends to be the most significant. As expected, the results exhibited in Tables 13 and 14 and 15 illustrate a strong significance of this variable. Table 16 shows that percentage of correct classifications was 78.3%.

In addition, it can be verified in Table 15 that the odds-ratio corresponds to 1.235 (from eq. (13), $\psi = e^{\hat{\beta}} = e^{0.211} = 1.235$). This means that when the bus driver's age increases by one unit, there is a 23.5% chance of his work ability falling to a range of poor to moderate (Y = 1).

Table 13: Model Fitting Information (A as independent variable)

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	63.671			
Final	38.101	25.570	1	0.000

Table 14: Likelihood Ratio Tests (A as independent variable)

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	64.734	26.633	1	0.000
A	63.671	25.570	1	0.000

Table 15: Parameter Estimates (A as independent variable)

	B	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
							Lower Bound	Upper Bound
Intercept	-9.721	2.721	12.760	1	0.000			
A	0.211	0.058	13.160	1	0.000	1.235	1.102	1.384

Table 16: Classification of the WAI percentage (A as independent variable)

Observed	Predicted		
	0.00	1.00	Percent Correct
0.00	21	5	80.8%
1.00	8	26	76.5%
Overall Percentage	48.3%	51.7%	78.3%

According to the parameters observed in Table 15, the simple logistic regression model, with *A* as the IV, can be expressed as follows:

$$Y = \frac{\exp(-9.721 + 0.211 \cdot A)}{1 + \exp(-9.721 + 0.211 \cdot A)} \qquad (16)$$

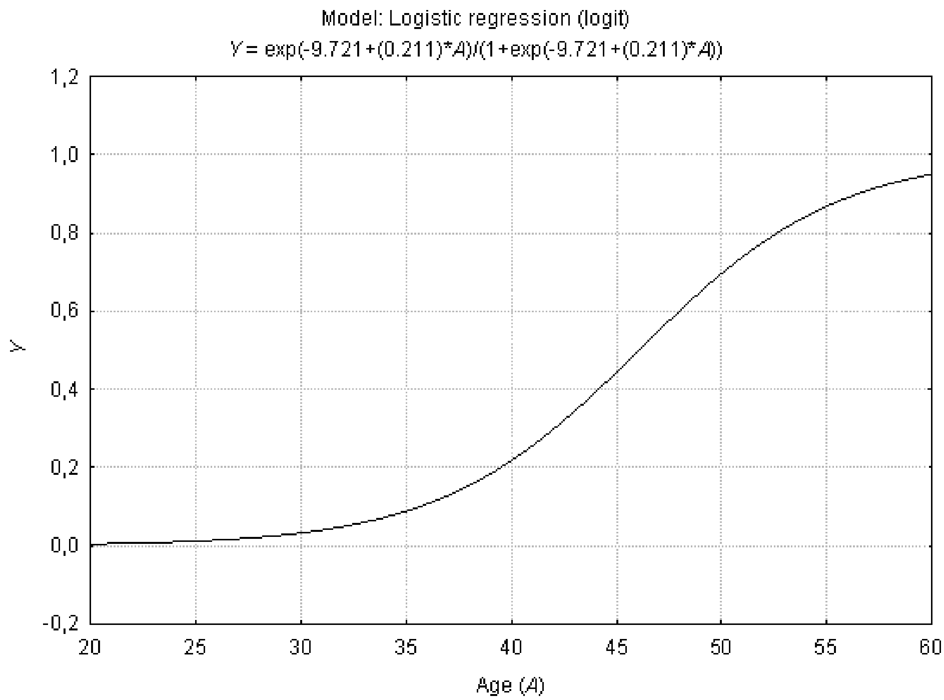

Figure 2: Logistic Function's Graph

Volume 4, Number 1, 2007, pp. 39-60

The logistic function can be observed in Fig. 2. It can be verified that the value of Y tends to 1 (WAI's range of poor to moderate) when the age of the bus driver increases.

According to Carvalho Filho and Papaléo Neto (2000), the thermal-regulation process becomes precarious with aging, affecting the efficiency of this mechanism and decreasing the heat tolerance in elderly individuals. Therefore, the high levels of thermal discomfort related by the older bus drivers can be referred to the losses in the efficiency of thermoregulation determined by the aging process, which in consequence can contribute to the work ability deterioration of these professionals.

Carvalho Filho and Papaléo Neto (2000) and Kauffman (2001) state that sympathetic reflexes of stress, which can be liberated by hearing stimulation like noise, determined "flight and fight" systemic reactions in the organism as a whole. Such reactions can cause an increase in arterial blood pressure, raise in heart rate, mobilization of the body's energy reserves as well as changes in alertness. These are some of the stress symptoms.

When this stimulus does not cause an immediate harm, the organism goes through successive adaptation processes and recurrent stress state, which can take the person either to a chronic stress state, or to a stronger adaptation. However, with the natural decline of the organic functions caused by aging, these mood changes are not easily supported by the organism (Kauffman, 2001). This leads to a chronic fatigue state, decreasing the tolerance to a noisy environment and contributing to their work ability loss.

The organic functions deterioration caused by aging, can be another explanation for older people to show high levels of discomfort related to noise and heat, and, because of that, they have shown lesser work efficiency. However, as physiological variables were not evaluated in this study, these considerations should be analyzed in greater depth in order to get a consistent result about the effects of noise and heat on elderly people.

The studies performed by Bellusci and Fischer (1999) with forensic workers, and by Boldori (2002) with firemen, have found the same relation between WAI and age as the one verified in this study. Nevertheless, they disagree with the result found by Kloimueller *et al*. (2000), who have found a low association between this variable and the urban bus drivers work ability.

The relation between age and work ability can be explained as a result of the natural aging process, which in fact confirms that the WAI is not satisfactory all life long, demanding long range studies involving frequent workers' evaluation.

Thus, age and discomfort related to noise and heat are somehow associated with the loss of the work ability of the urban bus drivers of the population studied.

6. CONCLUSION

Logistic regression has proven such a powerful analytical tool for quantitative assessment in the fields of epidemiology, health and ergonomics areas and it can also be applied in Production Engineering as well. It has been very much used, not only because its theoretical functions are simpler, but, mainly, due to its simple interpretation as a logarithm of the chance rate (odds ratio).

This technique was used to evaluate the work ability of urban bus drivers of the city of João Pessoa, Brazil. The statistical analysis showed that elderly people have a greater probability of having a moderate or low WAI, i.e., as the age of bus drivers increases the work ability decreases. And also when greater the discomfort feeling due to noise and heat, higher is the bus drivers' probability of presenting a poor to moderate work ability.

In this way, the biggest probability of a bus driver to show a low or moderate WAI was presented by the elderly ones, who have presented bigger discomfort regarding the noise and heat variables. The time of service did not show a relation with the work ability. These statements can be explained by the physical changes occurring during the aging process, which decrease the individual tolerance to the exposure to these environmental stress factors.

The elderly people's low tolerance to stress reactions caused by the noise and the deterioration of the thermal regulation mechanisms, can be the explanation for their having high discomfort levels related to noise and heat, and consequently low work ability levels.

However, in spite of these signs, physiological variables were not included in this research, which is a limitation. Hence, an investigation of these variables is recommended in order to obtain consistent results about the influence of the thermal and noisy environment on aging people.

REFERENCES

Agresti, A (1990), Categorical data analysis. John Wiley & Sons, New York.

Bellusci, S. M. and Fischer, F. M. (1999), Envelhecimento funcional e condições de trabalho em servidores forenses. Rev. Saúde Pública, Vol 33 No 6, pp. 602-609.

Boldori, R. (2002) Aptidão física e sua relação com a capacidade de trabalho dos bombeiros militares do estado de Santa Catarina. (Masters Dissertation). Programa de Pós-Graduação em Engenharia de Produção da Universidade Federal de Santa Catarina, Florianópolis.

Breslow, N. E. and Day, N. E. (1980), Statistical methods in cancer research. Volume 1 – The analysis of case-control studies. IARC Scientific Publication Number 32, Lyon.

Carvalho Filho, E. T. and Papalélo Netto, M. (2000), Geriatria: Fundamentos Clínica e Terapêutica. 2° Ed, Atheneu. São Paulo.

Casella, G. and Berger, R. L. (2002), Statistical inference, 2nd Edition, Duxbury, Pacific Grove, CA.

Cordeiro, R. (1991), Pressão Arterial Diastólica entre Motoristas e Cobradores de Campinas, Usuários de um Serviço de Saúde Ocupacional**.** (Masters Dissertation), Faculdade de Ciências Médicas da Universidade Estadual de Campinas, Campinas.

Cordeiro, R. *et al.* (2005), Exposição ao ruído ocupacional como fator de risco para acidentes do trabalho. Rev. Saúde Pública, Vol 39 No 3, pp. 461-466.

Costa, *et al.* (2003), Morbidade declarada e condições de trabalho: o caso dos motoristas de São Paulo e Belo Horizonte. São Paulo em Perspectiva, Vol 17 No 2, pp. 54-67.

Feuerstein, M. *et al.* (2003), Clinical and workplace factors associated with a return to modified duty in work-related upper extremity disorders, Pain, Vol 102 No 1-2, pp. 51-61.

Fleig, R. (2004)**,** Perda auditiva induzida por ruído em motoristas de caminhão de lixo urbano. Universidade Federal de Santa Catarina Programa de Pós-Graduação em Engenharia de Produção. (Masters Dissertation), Florianópolis.

Fogleman, M. and Lewis, R. J. (2002), Factors associated with self-reported musculoskeletal discomfort in video display terminal (VDT) users, International Journal of Industrial Ergonomics, Vol 29 No 6, pp. 311-318.

Hosmer, D. W. and Lemeshow, S. (1980), A goodness-of-fit test for the multiple logistic regression model. Communications in Statistics, A10, pp. 1043-1069.

Hosmer, D. W. and Lemeshow S. Applied logistic regression (1989), John Wiley & Sons, New York.

Karazman, R. *et al.* (2000) Effects of ergonomic and health training on work interest, work ability and health in elderly public urban transport drivers**.** International Journal of industrial ergonomics, Vol 25, pp. 503-511.

Kauffman, T.L. (2001), Manual de Reabilitação Geriátrica**,** Editora Guanabara Koogan, São Paulo.

Kelsey, J. L. *et al.* (1986), Methods in observational epidemiology. Oxford University Press, New York.

Kloimueller, I. *et al.* (2000), The relation of age, work ability index and stress-inducing factors among bus drivers. International Journal of Industrial Ergonomics, Vol. 25 No. 5, pp. 497-502.

Mello, M. T. *et al*. (2000) Sllep patterns and sllep-related complaints of Brazilian interstate bus drivers**.** Brazilian Journal of Medical and Biological Research, Vol 33, pp. 71-77.

Murphy, S. *et al.* (2007), A cross-sectional study of self-reported back and neck pain among English schoolchildren and associated physical and psychological risk factors, Applied Ergonomics, Vol 38 No 6, pp. 797-804.

Pimentel-Souza F. (2000), Efeitos do ruído no homem dormindo e acordado (Revisão).

Anais... XIXº. Encontro da Sociedade Brasileira de Acústica em Simpósio Internacional, SOBRAC-2000. Editores Vecci, Faria, Valadares e Valle. Belo Horizonte.

Rodrigues, L. O. C. and Magalhaes, F. C. (2004), Car racing: in the heat of competition. Rev Bras Med Esporte, Vol 10 No 3, pp. 212-215.

Rothman, K. J. (1986), Modern epidemiology. Little Brown – 1986, Boston.

Sampaio, R. F. *et al*. (2006), Avaliação da capacidade para o trabalho e estresse em uma empresa de Transporte coletivo de Belo Horizonte/Brasil, Ciência & Saúde Coletiva, to appear.

Schlesselman, J. J. (1982), Case-control studies. Oxford University Press, New York.

Shipp, E. M. *et al*. (2007), Severe Back Pain Among Farmworker High School Students From Starr County, Texas: Baseline Results, Annals of Epidemiology, Vol 17 No 2, pp. 132-141.

Werner, R. A. *et al*. (2005), Predictors of Upper Extremity Discomfort: A Longitudinal Study of Industrial and Clerical Workers, Journal of Occupational Rehabilitation, Vol. 15 No 1, pp. 27-35.

Zetterberg, C. *et al* (1987), Neck and upper extremity problems in car assembly workers. A comparison of subjective complaints, work satisfaction, physical examination and gender International Journal of Industrial Ergonomics, Vol 19 No 4, pp. 277-289.

Biography

Luiz Bueno da Silva, Dr.
Universidade Federal da Paraíba (UFPB)
Adjunct Professor of the Production Engineering Department
Address: Departamento de Engenharia de Produção (DEP) – Centro de Tecnologia – Campus I – Bloco G – Cidade Universitária, Castelo Branco, CEP: 58051-970 – João Pessoa, PB – Brazil – Caixa Postal: 5045.
Phone: (83) 3216-7685
Fax: (83) 3216-7549
e-mail: bueno@.ct.ufpb.br

Anand Subramanian
Universidade Federal da Paraíba (UFPB)
Masters Student (Programa de Pós Graduação em Engenharia de Produção – PPGEP)
Address: Departamento de Engenharia de Produção (DEP) – Centro de Tecnologia – Campus I – Bloco G – Cidade Universitária, Castelo Branco, CEP: 58051-970 – João Pessoa, PB – Brazil – Caixa Postal: 5045.
Phone: (83) 3216-7685
Fax: (83) 3216-7549
e-mail: anandsubraman@gmail.com
Francisco Soares Másculo, PhD.

Volume 4, Number 1, 2007, pp. 39-60

Universidade Federal da Paraíba (UFPB)
Associate Professor of Production Engineering Department
Address: Departamento de Engenharia de Produção (DEP) – Centro de Tecnologia – Campus I – Bloco G – Cidade Universitária, Castelo Branco, CEP: 58051-970 – João Pessoa, PB – Brazil – Caixa Postal: 5045.
Phone: (83) 3216-7685
Fax: (83) 3216-7549
e-mail: masculo@.ct.ufpb.br

Fernanda Diniz de Sá, MSc.
Centro Universitário de João Pessoa
Professor of the Phisioterapy Departament
Address: Departamento de Fisioterapia, Campus do UNIPÊ, BR 230 - km 22, Água Fria, CEP 58053-000, João Pessoa, PB – Brazil – Caixa Postal: 318
Phone: (83) 2106-9200
Fax: (83) 3231-1130
e-mail: fedinizsa@yahoo.com.br