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The Man-hour Estimation Models & Its Comparison of Interim Products Assembly for Shipbuilding

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Abstract—The Man-hour of products is the basic data for rational production plan. To estimate the man-hour of ship's interim products both reliably and accurately, three models for man-hour estimation are proposed in this paper. They are Simple Linear Regression Model and Multiple Linear Regression Model, as well as Artificial Neural Network Model. To evaluate the performance of the models, mathematical methods were used to express the reliability and accuracy of each model. The reliability of the model was represented both by the consistency of the error center with "0" and the consistency of the error distribution with normal distribution. The accuracy of the model was represented by the Residual Sum of Squares. It is verified that the Model of Neural Network can elicit more accurate and reliable results than others via analysis and comparison.
Keywords—Man-hour, Shipbuilding, Neural network, Linear regression model

1. INTRODUCTION

The man-hour quotation of products is the basic data for rational production planning, cost accounting, performance evaluation and vital in achieving high productivity. The assembly man-hour quotation accounts for about 30% to 50% of the total of shipbuilding man-hour quotation. Conventionally, man-hour estimation for assembling a new interim product was simply calculated as a function of weight, following this method, the simple linear regression model was developed. In that model, the weight of product is regarded as the only valuable of man-hour. But the assembly man-hour depends not only on the weight of product but also many other factors (Bunch, 1999). Thus, the multiple linear regression model was developed (Chou, 2001). Compared with simple linear regression model, the latter is more advanced in precision and application scope (Salenm, 1997).

Previous studies have been limited to simplified linear models, which are inadequate for application in current shipyard practices. In addition, the relations between man-hours and other independent variables are very complex, and are regarded as a system of none-linear and high order. Thus, it is almost impossible to be described under linear theory framework. This is due to the deep gap between the postulated condition and practical situation. Only a new model is established under the theory of nonlinear can this problem be solved.

The objectives of the research are to investigate the prevailing factors for man-hour of assembly by empirical analysis and to construct man-hour estimation model. Further more, application of these models will provide more accurate man-hour estimation and allow decisions to be made more rapidly and scientifically, thus enhancing the competitiveness and profitability of the shipyard corporations. The remaining three sections are devoted to the illustration of the objectives of the research: the linear regression model was introduced in section 2, in section 3, a man-hour model using neural network was proposed; The quantitative and qualitative comparison of the results of the three models is contained in section 4, while the last section is devoted to the conclusions.

2. LINEAR REGRESSION MODEL

Conventionally, linear regression model is one of the most widely used statistical techniques to describe and predict the relationship between man-hour and factors associated to the man-hour. The linear regression models include simple linear regression model and multiple linear regression models. Datum in Table 1 show the product characteristics and man-hour of 28 samples, which were randomly collected on spot.

Table 1. The Characteristic & Man-hour Data of Samples

No.	M (Kg)	S (m^2)	L (m)	Man-hour T
1	258	1.54	2.42	0.65
2	202	2.61	2.72	0.66
3	249	3.17	3.28	0.67
4	398	4.64	5.44	0.7
5	1203	10.17	4.62	0.7
…	…	…	…	…
24	1105	11.91	21.46	1.81
25	849	7.9	14.54	1.82
26	770	7.15	15.65	1.85
27	805	8.25	20.05	1.94
28	838	8.04	16.23	1.94

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Here, M_i is the weight of product i; S_i is projective area of product i; L_i is the length of welding line of product i; T_i is assembly man-hour of product i.

2.1 Simple linear regression model

Simple linear regression model is described as follow,

$$T_i = \beta_0 + \beta_1 \times M_i + \varepsilon_i$$

T_i is man-hour for assembly the product i, (man-hour),
M_i is the weight of product i (Kg;),
β_0 and β_1 are regression coefficients;
ε_i is error term.

Table 2. the Result of Simple Linear Regression

β_0	β_1	S_e	S_A	S_T	R^2	F
0.55	0.096	2.93	2.56	5.48	0.44	22.7

S_e is the value of residual sum of squares;
S_A is the value of sum of squares about regression:
S_T is the value of deviation sum of squares;
R^2 is the value of fittings, denoting the effects of independent variable on assembly man-hour;
F is a statistic value for denoting the reliability of the model.

As shown in Table 2, it can be seen that the significance level of linear relationship between man-hour and the weight of products is very high, F is equal to 22.7. This indicates that weight and man-hour do have positive correlation. Thus, it can be concluded that the conventional method of man-hour estimation is rational in some degree. But on the other hand, the fitness value (R^2) is small than 0.44, means that only about 40 percent variance of assembly man-hour is caused by weight of product, while about 60 percent variance result in other factors omitted. Then, to improve the correctness of man-hour model, it is reasonable to design a new model covering more factors concerned man-hour. As a result, a multiple linear regression model comes forward.

2.2 Multiple linear regression model

Multiple linear regression model is as follow:

$$T = \beta_0 + \beta_1 \times M + \beta_2 \times S + \beta_2 \times L + \varepsilon_i$$

T_i is assembly man-hour of product i, man-hour;
M_i is the weight of product i, Kg;
S_i is projective area of product i, $m2$;
L_i is the length of welding line of product i, m;
β_0, β_1, β_2 and β_4 are regression coefficients;
ε_i is a random error term.

Three parameters were selected as the independent variables for assembly man-hour estimation. They are weight, length of welding line and projection area of product. The results of Multiple Linear Regression Model are showed in Table 3.

S_e is residual sum of squares of error term:
S_A is sum of squares about regression of error term;
S_T is deviation sum of squares of error term;
R^2 is fitted value, which denoting the effects of independent variable on assembly man-hour;
F is a statistic value for denoting the reliability of the model.
$t(1)$, $t(2)$, $t(3)$ are statistics, which denoting the independency level among independent variables.

Table 3. The Result of Multiple Linear Regression Model

β_0	β_1	β_2	β_3	S_e	S_A
0.54	0.026	-0.07	0.09	0.53	4.95
S_T	R^2	F	$t(1)$	t (2)	t (3)
5.48	0.90	74.9	1.36	-3.2	10.3

As shown in Table 3, the value of R^2 reached 0.90, which is far higher than that in Table 2. It means that about 90 percent variance of man-hour is caused by the three factors aforementioned. Compared with simple linear regression model, the description capability of multiple linear regression model is more comprehensive. The ratio of man-hour variance, caused by omitted factors, reduced from about 50 percent to 10 percent.

As shown in Table 3, the values of $t(1)$, $t(2)$ and t (3) are small. It means that the independency among independent variables is not significant. In other word, some nonlinear relationships exist among them and it's more complex and can be explained by this model. In this case, to estimate assembly man-hour more accurately, it is necessary to develop a new model based on other theories and techniques.

3. ARTIFICIAL NEURAL NETWORK MODEL

There's a complex multiple nonlinear relationship between assembly parameters and its man-hour, which is rather difficult to deal with in the theory of linear regression. A new theory or technology is needed to solve this problem. In this paper, artificial neural network (ANN) with a back propagation algorithm is proposed for the generation of man-hour, and it is verified with some examples in solving the non-linear high order problems.

3.1 BP (Back Propagation) neural network

ANN is biologically inspired and is confirmed as an effective algorithm. The technique deduces desired parameters by relating learned functions to knowledge processing and pattern recognition. The fundamentals and practices of ANN are found in many books, such as, (Freeman, 1991).

The BP Network is chosen to map assembly man-hour and its parameters of products, and then generate the man-hour of each. Figure 1 shows a conceptual diagram for an application of artificial neural network.

As show in Figure 1, the process of man-hour estimation using artificial neural network is constituted of three steps. In the first step, man-hour data are collected on spot, and put into man-hour database; in the second step, the neural network will be trained using the data of parameters and man-hour of samples which was collected in the first step; in the third step, the assembly man-hour of new products will be generated using the network which was trained in step 2.

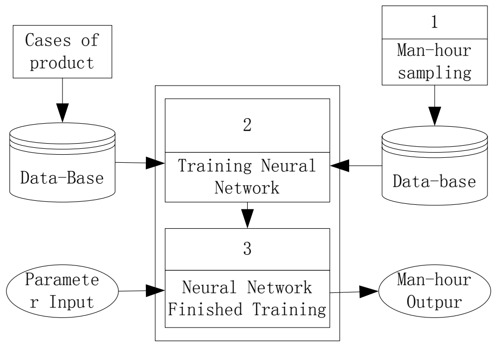

Figure 1. A conceptual diagram for application of neural network.

A three layer network model was developed, following the theory (Hecht-Nielsen, 1989) that any L2 function transformation from [0, 1], *n* to Rm can be implemented to any desired degree of accuracy with a three layer back propagation neural network. The input layer is consisted of three neurons corresponding to the three input parameters, while the output layer is consisted of a single neuron producing the desired man-hour estimate. The number of neurons in the hidden layer was found by trial and error since "the number of hidden units per layer is more of an art than a science" (Karayiannis, 1992). A sample of 28 different products was used. The rate of training ranging from 0.01 to 1.0 and the iteration is 10,000. The following Figure 2 is the network structure.

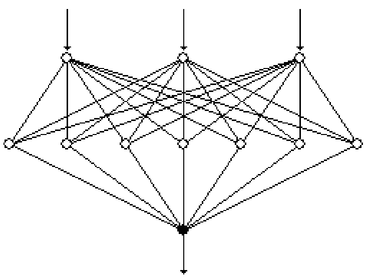

Figure 2. The Structure of Neural Network.

The process of training via this model is showed in Figure 3. In this figure, axis Y is error of the model, while axis X is iteration of training. As the iteration becomes larger and larger, the error converged quickly.

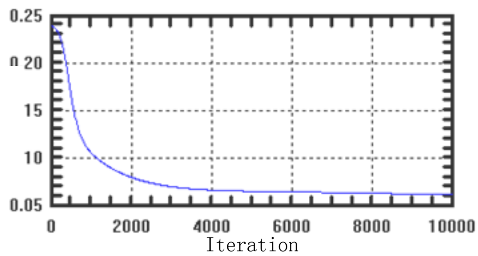

Figure 3. Convergent Cure of error.

3.2 Man-hour generation

The precision of the model is very high after the training of 10,000 iterations, and sum of squares (MSE) about error term is close to zero with a value of 0.0139. A scattergram of neural network predicted man-hour vs. line of man-hour collected on spot is shown in Figure 4. The graph shows that the neural network's predictions is close to the actual man-hour.

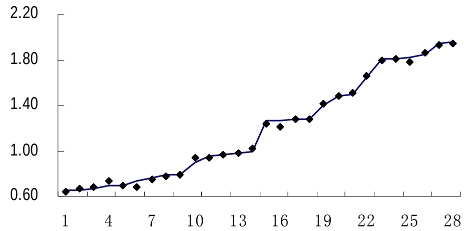

Figure 4. Target/Output VS Pattern Number.

4. COMPARISON OF VARIOUS MODELS

The aims of the establishment of a model include as follow (1) the description and explanation of a relationship among variables by estimating the model parameters, and (2) the prediction of the dependent variable values given the levels of independent variables. In this section, the correctness and preciseness of simple regression model, multiple regression model and neural network model are compared. And the technique for the comparison is mainly based on error theory, statistics theory combined with characteristic of assembly process. The data and results of each model are analyzed, to find out the statistical laws, and then analyze the distribution shape of data. Then the performance of each model will be compared based on the statistical values.

Table 4. The description of Model Codes

Model Code	The describe of the Model Code
SLR	Simple Linear Regression Model (SMR) between the man-hour and product weight.
MLR	Multiple Linear Regression Model of L, S, M and T
NN	Neural Network Model (NN) of L, S, M and T

4.1 Residual sum of squares—S_e

The value of residual sum of squares of term error (Se) reflects the degree of precision of a model, the bigger the value, the bigger the imprecision of model, and the lower the degree of precision. On the contrary, the smaller the value is, the higher the degree of precision. The value of Se of different models is shown in the following table.

Table 5. The Residual Sum of Squares (RSS) of Models

Model Code	SLR	MLR	NN
Residual sum of square—S_e	2.93	0.53	0.0139

As shown in Table 5, the value of Se of simple linear regression model is highest, and that of multiple linear regressions model is in medial, the Se of the NN is the smallest. This proved that the error of NN model is lowest, and the degree of precision is highest. And the error of simple linear regression model is the biggest; the degree of precision is the lowest.

4.2 Distribution shape of errors

As mentioned above, the method-using Se to evaluate the performance of a model is distinct. But it couldn't give the distribution shape of error term of a model. We know, distribution shape of error term is an important characteristic for model performance. So it is not sufficient to evaluate models only based on the statistics of Se. And it is necessary to evaluate the distribution shape of error term. Figure 5 shows the distribution shape of error terms of different models. Here we can see, error distribution of different models has significant difference. With the improvement of the model, (1) ratio of sample with smaller error is ascending, while the ratio of the bigger ones is descending; (2) the error range becomes narrow; (3) the error center is closer to zero; and (4) distribution shape is closer to normal distribution. Is these difference contingent?

According to the theory of error, any results of estimate can be expressed by:

$$y_i' = y_i + \varepsilon_i$$

y_i' is the valued of estimated man-hour of the sample i;

y_i is the value of measured man-hour of the sample i;

ε_i is the value of error term;

i is the code number.

Errors ε consist of systematic error and chance error. In general situation, systematic error is greatly bigger than chance error, and it determines the correctness of estimated results, while the chance error reflects the degree of estimation precision. The narrower the fluctuating error range, the more precise the estimated results. However, systematic error is always hidden in measure results, and it is difficult to make out. Thus, the systematic error is more dangerous than chance error. Generally, the systematic error is mostly caused by the imperfect relationship, the techniques and methods for model establishments. While on the contrary, a chance error is caused mainly by unconcerned, distinct, ruleless factors, in general, their influence on the estimated value is slight and difficult to predict. This showed that: (a) chance error results from multiple factors; (b) these factors are independent and unrelated to each other; (c) every fact alone has a slight effect on the final error. In another words, one factor has no significant effect, if there is, its effects are equal and small. These are agreed with 'Lyapunov condition. In such a case, the error term should present its corresponding statistic law----normal distribution law.

As analyzed above, the correctness of a model depends on whether the model has systematic error in the model. And the precision of a model depends on the value of chance error. A model should not have any systematic error. So the systematic error must be eliminated from the model, or be eliminated enough to be neglected. Only in this way, a model is correct. Under this condition, the errors of a model are mostly comprised of chance error. Then, the error of a model should represent characteristic of chance error—normal distribution with mean of zero.

4.3 Normal distribution test of errors

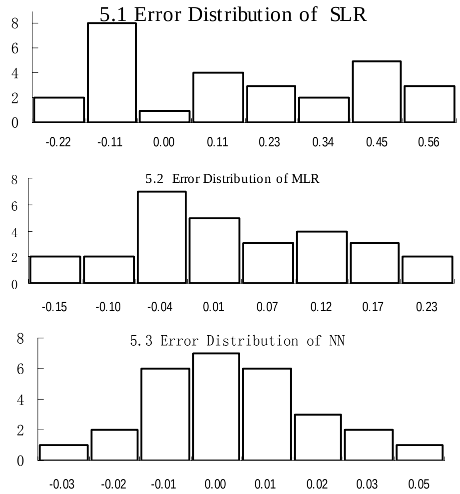

Figure 5. The Error Distribution of Models.

As mentioned above, estimated results of the model are correct only on the condition that there is no systematic error, if there is, it is small enough to be neglected. In that case, the errors of model are mainly consisted of chance error, which is normally distribution with mean of zero. In another words, there will be no systematic error in the model if the error of the model obeys normal distribution with mean of zero. Hence, the correctness of the model can be test through the distribution shape of the error test of the model. If the error is normally distribution with mean of zero, the model should be correct.

The test of normality distribution of the three models will be carried out, and the method of x^2 fit test was stated by a mathematician, K. Porison.

The processes are:

1. Divide the error term into k inconsistent smaller ranges according the value of them.

$$A_1 = [a_0, a_1), \ldots A_i = [a_{i-1}, a_i), \ldots A_k = [a_{k-1}, a_k]$$

2. Calculate the observe value of x^2, which is computed as:

$$x^2 = \sum_{i=1}^{k} \frac{\left(n_i - n\hat{p}_i\right)^2}{n\hat{p}_i}$$

n is the sample size;

n_i is the frequency that sub-samples which belong to range A_i.

$\hat{p}_i$ is the estimator probability that parent population which belong to rang A_i;

$\hat{p}_i$ is the probability of sub-sample which belong to A_i.

m is the number of parameters in probability function of samples. (For example, there are two parameters in normal distribution function: expected mean and variance).

3. Given a certain confidence coefficient, for example, α = 95%, and Degree of freedom, $v = k - m - 1$, search it in the table for x^2 distribution. Then get the critical value x^2_α. Compare the observed value of x^2 with the critical value of x^2_α. If the observed value is smaller than the critical value, then the error term obeys normal distribution.

To test whether the error term of the three models (SLR, MLR and NN) mentioned above is normal distribution, first, we divide the original data of each error term into 8 ranges, given a confidence coefficient α =95%; then calculate corresponding observe value of x^2. In the end, from the table of x^2-distribution, we get the value of $x^2_\alpha(8-2-1)$. Compare the observe value x^2 with corresponding critical value $x^2_\alpha(5)$, a conclusion is made that whether the distribution of each error term agree with normal distribution.

Table 6. The Test of Normal Distribution of Models

	SLR	MLR	NN
Observed Value x^2	25.58	5.24	2.77
Critical Value $x^2_{0.95}$	11.07	11.07	11.07
Confidence Coefficient α	0.95	0.95	0.95
Normality Test, Pass or not?	NO	PASS	PASS

As shown in Table 6, the error term of simple linear regression model didn't pass the test of normality. While the error terms of multiple linear regression model and artificial neural network model passed. That means that model of SLR has systematic error, while the other two may not. To ensure models, MLR and NN, do not has systematic error, it is necessary to make a consistency check, yet.

4.4 Consistency test between mean error with zero

According to the analysis above, that the distribution shape of error term of a model obeys normal distribution is a necessary condition rather than sufficient condition. To ensure there is no systematic error, if there is, its systematic error is small enough to be neglected in the model, it is necessary to make a consistency check. In another words, on the condition that the errors distribution shape obeys normal distribution, it's necessary to test whether the error center (mean) is close to zero or not. This test is also called consistency check between error mean and zero. Here, the method is test. It is to say, the object of this test is to confirm the consistency between error mean and zero on condition of a certain confidence coefficient, for example, α =95%.

The formulation of calculating the Statistic t:

$$t = \left| \frac{\bar{\varepsilon} - 0}{S_n} \right| \times \sqrt{n}$$

$\bar{\varepsilon}$ is error mean; n is sample size; S_n is sample variance.

Table 7. The Consistency Check of Models' Error Center

	MLR	NN
confidence coefficient α	95%	95%
Observed Value t	<0.1	<0.01
Critical Value $t_{0.95}$	1.7081	1.7081
Consistency check, pass or not?	PASS	PASS

Table 7 shows the consistency check results of error mean with zero of different models. As shown in the table, the observed values of MLR Model and NN are greatly less than the critical value, 1.708. This result suggests that both error means of the two models have passed the consistency check. Further more, it gives proof that the systematic errors of the two models are too little to be neglected, or even there is no systematic error.

4.5 Comparison of precision

The above analysis indicates that the error term of the models (MLR, NN) is normally distributed with mean of zero. It means that there is systematic error in the model or it is little enough to be neglected. That is to say, the estimated results are correct and reliable. Hence, an interesting question arise, which, MLR model or NN model, would be a choice under such circumstance. It is known that the value of Residual sum of squares (S_e) of error term reflects the precision of a model. The smaller the value of S_e is, the more precise the model. But when the values of S_e of two models are different, are their precisions significant different? Can we say the precision of a model with smaller S_e is greatly more significant than the other one with bigger S_e ? This problem can be solved by mathematical and statistical methods. And how to make a conclusion whether the value of S_e of two models is significant? In other words, is the model with a smaller S_e more greatly precise than another under a certain confidence coefficient, for example, α = 95%r? Statistic F can use to check that.

the formulation of calculating the Statistic F:

$$F = \frac{S^{*\,2}_{1_{n_1}}}{S^{*\,2}_{2_{n2}}} = \frac{\frac{1}{n_1 - 1} S^2_{n_1}}{\frac{1}{n_2 - 1} S^2_{n2}}$$

$S^2_{n_1}$ is sample variance of error term ε_1 from model 1;

$S^2_{n_2}$ is sample variance of error term ε_2 from model 2;

n_1 is sample size of model 1;

n_2 is simple size of model 2.

As shown in Table 8, in this case, the critical value is 1.93, while the observed value of statistic F is 38.25 >> 1.93. The two values of Se of the two models are significant difference with confidence coefficient 95%. Also in this way, it can be assumed true that the S_e value of Multiple Linear Regression Model is bigger than that of Artificial Neural Net Work Model. That is to say, the precision of ANN model is greatly higher than that of MLR model.

Table 8. The Results of F check

	MLR	NN
Confidence Coefficient α	95%	95%
Sample variance S_n^2	0.53	0.0139
Observed value of F	38.25	
Critical Value of $F_{0.95}$	1.93	
Is there significant difference?	Yes	

5. CONCLUSIONS

To estimate the assembly man-hour of vary products in shipbuilding both correctly and precisely, three models are proposed in this article, namely, simple linear regression model, multiple linear regression model, and artificial neural network model. And the descriptive capability is compared. The main finding in this paper maybe summarized as follows:

(a) While estimating the assembly man-hour of the intermediate products, Systematic errors of Linear Regression model and Artificial Neural Net Work Model are so little that they can be neglected.

(b) The precision of Artificial Neural Network Model is better than Multiple Linear Regression Model.

Comparing, the descriptive capability of Artificial Neural Network Model is far better than the other two models, and the assembly man-hour estimated using it will be more correct and precise.

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