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A method for the quantitative correlation between quality requirements and product characteristics of sport equipment.

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Abstract

Each sport equipment is evaluated by the users through different categories of quality requirements and by the R&D team using a set of engineering parameters. In previous studies the correlation between the quality requirements and the engineering characteristics was obtained by means of methods based on arbitrary judgment such as OFD [1]. Aim of the work is the development of a method for a quantitative correlation between the quality requirements and the product characteristics of sport equipment. The method was developed considering the racing bicycle wheels. A structured and objective method for collecting the user’s quality requirements was developed and a subjective evaluation test session was performed for collecting the cyclists’ evaluation of different wheels models. The correlation coefficients were calculated adopting the Pearson’s coefficients computation method. The results didn’t show any inconsistency and the high and the low correlation coefficients agreed with the expected analysis of the bicycle riding dynamics. The paper presents a structured and innovative approach to the study of the link between the users’ world and the technical characteristics of sports equipment.

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Keywords: subjective evaluation test; QFD quality function deployment; ODI outcome driven innovation; bicycle wheels.

1. Introduction

Each sport equipment is evaluated by the user and by the R&D team from two different points of view. The **user** formulates his evaluation considering different quality requirements which can be divided into the following five macro-categories: usability, comfort, performance, safety and aesthetic/emotional

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parameters. The evaluation of the R&D team refers to the product characteristics such as the architecture characteristics, the technological characteristics and the engineering parameters measurable by means of laboratory tests.

QFD (Quality Function Deployment) [1] and ODI (Outcome Driven Innovation) [2] methods propose some structured procedures for the collection and organization of user's quality requirements. QFD method involves also a method and some tools for a correlation between them and the product characteristics obtained from arbitrary judgments based on shared experience. In previous studies (J.Darques *et al.* [3], P. Clifton [4], P. Clifton *et al.* [4]) the correlation between the user's quality requirements and the product characteristics of sport equipment was investigated and, for this purpose, the QFD approach was adopted. The correlation coefficients so obtained result from the considerations of the analyst or of the analyst group, they have therefore arbitrary features.

Aim of this work was the development of a method for a quantitative correlation between the quality requirements and the product characteristics of sport equipment. The method was developed considering the racing bicycle wheels and focusing on the correlation between the wheels quality requirements perceived by the cyclists during road cycling, and the engineering characteristics measured by means of laboratory tests (mass, inertia, stiffness, engineering complex indexes). This work follows our previous studies on wheels technical characterization in which the radial structural behavior and the comfort properties of racing bicycle wheels were investigated (N. Petrone, F. Giubilato [6], [7], [8]).

2. Method

The overall method was developed in order to minimize the analyst's subjective influence and therefore maximize its repeatability. The method development process was divided into three main stages:

- development of a structured method for discovering and organizing the wheels quality requirements evaluated by the cyclists during road riding;
- organization and execution of subjective evaluation tests in order to collect the cyclists assessment on quality requirements of different wheelsets;
- development of a mathematic method for computing the correlation coefficients between each quality requirement and each engineering characteristic and overcoming, by this way, the arbitrary feature of QFD.

2.1. Method developed for discovering and organizing the wheels quality requirements

The "jobs-to-be-done" theory proposed in ODI [2] was adapted for collecting and organizing the perceived quality requirements of racing wheels evaluated by the cyclists. The theory drive the attention on which goals costumers are trying to reach or which problem they are trying to solve in a given situation. It analyzes the user's point of view with a schematic approach. This theory and the relative structured method proposed in ODI for discovering the customers' needs with respect to a considered product was conveniently adapted for the purpose of this work. The developed method follows the scheme showed in Figure 1:

1- identification of the actions performed by the cyclist during racing bicycle riding;
2- identification of the consecutive phases in which each action can be divided;
3- identification of the metrics, or evaluation parameters, used by the cyclists for evaluating the goodness of the outcome of each action's phase.

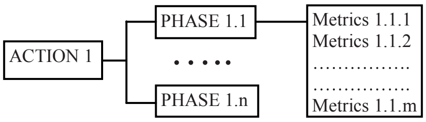

Fig. 1. Schematic of the developed method

Twelve typical actions performed by the cyclists during racing bicycle riding and a total of 35 metrics adopted for their evaluation were identified, after an observational analysis, by personal and group interviews to 13 cyclists selected from different categories (racers, high level amateurs, low level amateurs):

During subjective evaluation tests, each tester was asked to express an assessment about the performance of the tested wheels through the metrics which were identified to be typical of cyclists.

The evaluations expressed by the testers through the 35 metrics were combined to obtain the evaluation of 7 wheels quality requirements. They summarize the testers' evaluation on wheels performance and they result to be easier to manage during the reporting activity than the 35 metrics. The connection between each metric and each performance parameter was established following the logical relationship between their respective definition. This can be represented by a net of relationship in which each metric can contribute to the evaluation of one or more performance parameter and the assessment of each performance parameter can be obtained from the contribution of one or more metrics (Fig. 2). An example of an action, its consecutive phases, the corresponding metrics and the metrics/quality requirements relationship is showed in Figure 2.

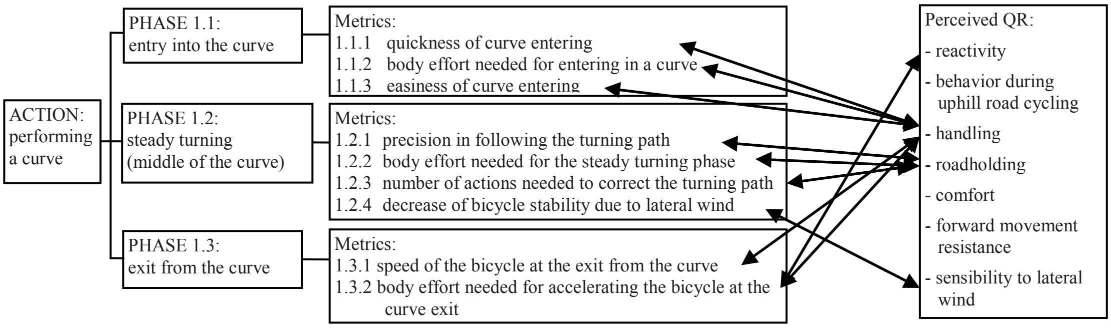

Fig. 2. Turning action: phases, metrics and metrics/quality requirements relationship.

2.2. Subjective evaluation tests

A subjective evaluation test session was organized and carried out in order to collect the cyclist evaluations on the perceived quality requirements of 3 different wheelsets.

The three wheels models selected represent, among the models available for the research team, the models with the highest differences with respect to the greater number of engineering characteristics measured in laboratory tests. Table 1 shows the constructive and the engineering characteristics of the selected wheels, their engineering characteristics normalized with respect to the best value are showed in Figure 3.

Table 1. Constructive and engineering characteristics of the three wheelset selected for the subjective evaluation tests.

Wheelset	Constructive characteristics			Basic engineering characteristics measured in laboratory				
	Rim depth	Rim material	Spokes Nr. and Pattern Front Rear	Mass Front Rear [g]	Inertia Front Rear [kg·m^2]	Lateral stiffness Front Rear [N/m]	Torsional stiffness Rear [N/m]	Radial stiffness [5] Front Rear [N/m]
 A	High H 105 mm	Composite	16 radial 18 triplets	873 1025	$5.96\cdot10^{-2}$ $6.19\cdot10^{-2}$	$48\cdot10^3$ $41\cdot10^3$	$4.98\cdot10^3$	$4.81\cdot10^3$ $3.94\cdot10^3$
 B	Medium H 35 mm	Aluminium	16 radial 21 triplets	653 868	$4.74\cdot10^{-2}$ $5.43\cdot10^{-2}$	$50\cdot10^3$ $54\cdot10^3$	$5.44\cdot10^3$	$2.36\cdot10^3$ $2.55\cdot10^3$
 C	Low H 20 mm	Composite	22 radial 24 2x	589 771	$3.91\cdot10^{-2}$ $4.27\cdot10^{-2}$	$44\cdot10^3$ $42\cdot10^3$	$5.26\cdot10^3$	$1.95\cdot10^3$ $1.96\cdot10^3$

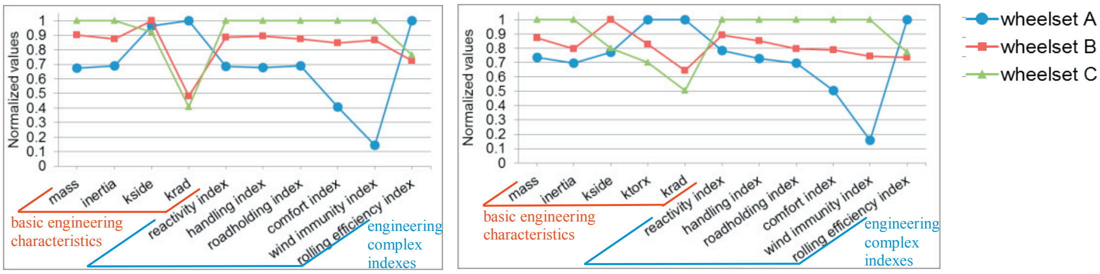

Fig. 3. Normalized engineering characteristics (mass, inertia, stiffness, engineering performance indexes) measured for front (a) and rear (b) wheels.

Thirty-three cyclists took part to the tests. They were selected from different categories (ranging from professional and amateur racers to low level amateur) in order to get a representative and unbiased sample [9]. During the tests each cyclist had to ride once for each wheelset the same road path , 12 km long, 260 m altitude gap gradient, presenting most of the typical situations encountered during road cycling (Fig. 4.a) such as steep and medium slope uphill, straight descent road, descent road with curves, flat road, road with obstacles etc. At the end of each run each tester had to answer to a questionnaire with multiple choice answers for evaluating the outcome of the 12 actions performed with the tested wheelset. For each question the tester had to express his assessment trough the metrics individuated as explained above, the Likert scale from 1 to 5 was adopted. The structure of the queries (Fig. 4) allows the tester to express his opinion on the three wheelset adopting a relative scale for minimizing, in this way, the effect of his experience and his cycling history. For increasing the reliability of the answers, each question gives also the optional answer “I could not feel what is requested” and also in some cases “I have not done this action during the test”.

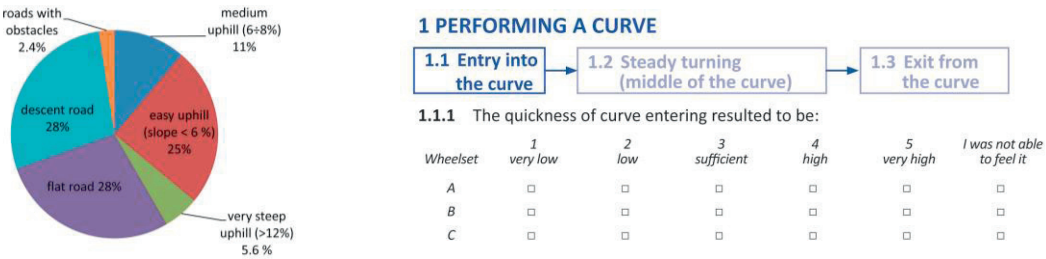

Fig. 4. (a) characteristics of the selected road path ; (b) example of a multiple answer question inserted into the questionnaire.

2.3. Data analysis

A Matlab® program was developed for the statistical analysis of the questionnaires results and for the computation of the correlation coefficients as explained above.

The average difference between the votes given by the testers to each tested wheelset and the votes given to the tested wheelset evaluated as to be the worst was calculated for each query or metrics in order to obtain an evaluation of the tested wheels in a relative scale. The assessment of each performance parameter was calculated as the average of the votes given by the testers to the afferent metrics (Fig. 2).

The correlation coefficients between the quality requirements (QR) and the engineering characteristics (EC) were calculated applying the Pearson's coefficients computation method [9]. A diagram was prepared for each QR_i/EC_i couple in which the average differential votes given by the testers to QR_i and the values measured for EC_i were respectively reported in the x and y axis (Fig.5). Each tested wheelset was therefore represented on the diagram by a point and the QR_i/EC_i correlation coefficient was calculated as the R parameter of the linear least square fitting curve. The correlation coefficients were reported on a matrix with the structure of the "House of quality" correlation matrix proposed in the QFD method [1]. The sign of the correlation coefficients indicates if the QR_i/EC_i correlation is direct (+) or inverse (+), the correlation is high if $|R|>0.9$, medium if $0.7<|R|<0.9$, low if $|R|<0.7$ and there is no correlation if $|R|<0.5$.

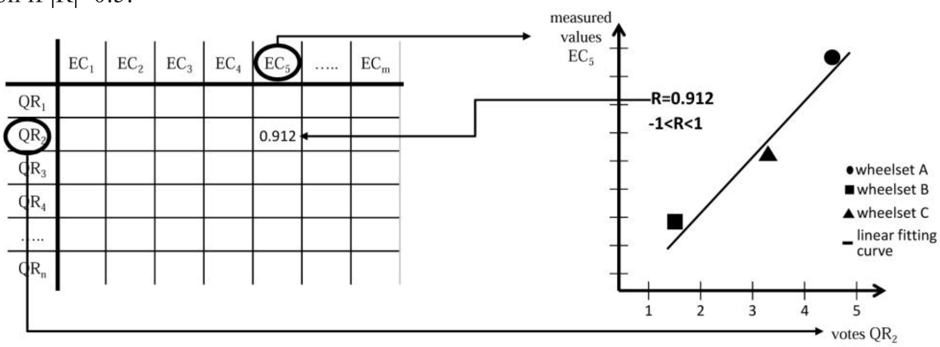

Fig. 5. Computation of the correlation coefficients.

3. Results and discussion

The average standard deviation between the votes given by different testers to the same wheelset is equal to 0.84 votes for the absolute votes and to 0.77 votes for the differential votes. The lower dispersion of the differential votes confirms that asking the testers for an evaluation expressed adopting a relative scale is more reliable. Low correlation coefficients (<0.7) were calculated between the perceived quality requirements and the engineering characteristics which were expected to do not influence the dynamic behavior of the wheels, such as the lateral and the vertical truing. Correlation coefficients greater than 0.9 were calculated between each performance parameter and the related engineering complex index developed in order to express a technical measurement of it. This was assumed as a validation of the methods developed for the engineering complex indexes computation which formulation will be the content of a future publication. In some cases the interdependence between the different engineering characteristics causes high QR_i/EC_i correlation coefficients which have to be considered not significant. For some perceived quality requirements the correlation coefficients calculated with all the engineering characteristics resulted to be low: this suggested the need for developing additional measurement method of engineering characteristics.

4. Conclusions

The structured features of the user-centered method developed for collecting and organizing the quality requirements of sport equipment minimize the influence of the analyst and enhance the characteristics of repeatability. The subjective evaluation test method, the choice of the road path and the querying method resulted to be suitable for the purpose of this work and appreciated by the testers. The computation method developed for the correlation coefficients allows to obtain a quantitative correlation, based on statistics and experimental evidence, between the quality requirements and the engineering characteristics of sport equipment. This aspect represents a significant improvement of the method proposed by QFD [1]. The results didn't show any inconsistency and the high and low correlation coefficients agreed with the expected analysis of the bicycle riding dynamics.

The overall approach resulted to be suitable for the scope: methods developed are applicable to other sport equipment.

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References

[1] Y. Akao, *QFD: Quality Function Deployment - Integrating Customer Requirements into Product Design*. Productivity Press, 2004, Portland. p 1-83, 147-181.

[2] Anthony W Ulwick, *An Introduction to Outcome - Driven Innovation*, Strategyn Inc.

[3] J.Darques, R. Carreira, A. De La Mettrie, D. Bruyant, *Quality Function Deployment - A means for developing adequate skis and snowboards*, 2004, The Engineering of Sport 5 - Conference Proceedings of the Engineering of Sport, pp. 428-434. Davis, USA.

[4] P. Clifton, *Investigation and Customisation of SnowboardPerformance Characteristics for DifferentRiding Styles*, 2011, PhD thesis School of Aerospace, Mechanical and Manufacturing Engineering, College of Science, Engineering and Health, RMIT University.

[5] P. Clifton, M. Burton, A. Subic, T. Perret-Ellena, A. Bedford, A. Schembri, *Identification of performance requirements for user-centered design of running shoes*, 2011, 5th Asia-Pacific Congress on Sports Technology - Procedia Engineering 13, pp. 100-106.

[6] N. Petrone, F. Giubilato, *Methods for evaluating the radial structural behaviour of racing bicycle wheels*, The 5th Asia Pacific Congress on Sports Technology, 2011.

[7] N. Petrone, F. Giubilato, *Comparative analysis of wheels vibration transmissibility after full bicycle laboratory tests*, AIAS Conference, 2011.

[8] F. Giubilato, N. Petrone, *A method for evaluating the vibrational response of racing bicycles wheels under road roughness excitation*, 2012, The Engineering of Sport 9 - Conference Proceedings of the Engineering of Sport, pp. 409-414. Lowell, USA.

[9] W. J. Vincent, *Statistics in Kinesiology*, California State University, Northridge; Human Kinetics