

Concept design in virtual reality of a forestry trailer using a QFD-TRIZ based approach

Kenan MELEMEZ¹, Giuseppe DI GIRONIMO^{2,*}, Gianpiero ESPOSITO², Antonio LANZOTTI²

¹Forest Engineering Department, Bartın University, Bartın, Turkey

²Department of Industrial Engineering, University of Naples Federico II, Naples, Italy

Received: 06.02.2013 • Accepted: 21.04.2013 • Published Online: 23.09.2013 • Printed: 23.10.2013

Abstract: Trailers are used to carry logs having specific dimensions for logging extraction operations, secondary transportation, and agricultural activities. The main objective of this study was the design of a timber trailer capable of manual loading operations and suitable for rough terrain conditions to be used in combination with a farm tractor in the western Black Sea region of Turkey. In the proposed methodology, a House of Quality diagram was used to transfer customer requirements into quality characteristics, and focus the development of the product toward customer satisfaction. Negative correlations between quality characteristics were solved using the TRIZ contradiction toolkit and generating different concepts. Inventive solutions provided by TRIZ were designed with parametric CAD software. Several concepts were compared in a participative design review session in an immersive virtual reality environment. To choose an optimal concept, the analytic hierarchy process (AHP) was used. The final concept has a total length of 3.35 m, width of 1.34 m, and height of 1.8 m. The mass is 2700 kg, the payload capacity is about 2.33 m³, and the total volume of the chassis is 2.68 m³. The angle of rollover is 26.9°, the door is reachable by 90% of the population, and the lower back analysis performed for the loading operation showed a maximum value of 2597 N. The final concept is capable of movement in steep terrain and with the presence of obstacles, carrying logs up to 3-m long. It is more productive among high-density stand trees, allows for ergonomic loading operations, and reduces environmental damage to soil and vegetation.

Key words: AHP, ergonomics, forest harvesting, interactive design, QFD, TRIZ

1. Introduction

The application of mechanized equipment for harvesting purposes in most regions of Turkey is currently limited due to the fact that labor costs are low and fuel costs are high (Akay et al., 2004). Forests are generally located in mountainous areas with difficult terrain conditions (Tunay, 2006). Forest machinery is purchased on the foreign market (Öztürk, 2010). However, forest machines and equipment are usually designed to suit the working conditions of the manufacturer's home country; therefore, when purchasing these machines, it is not sufficient to make decision on the basis of factory data and productivity described in foreign literature (Sabo and Porsinsky, 2005). The reason for this lies in the specific relief and climate features of Turkish forests, as well as in the diversity of tree species, condition of stands, and manner of forest management. The harvesting system has to be chosen by considering the forest characteristics, machine type, and intensity of the harvest operations to reflect variable factors that affect the productivity of the equipment. In a study by Akay et al. (2004) based on data representing the economic conditions in Turkey, it

was reported that a forwarder system has the potential to produce wood at a lower cost than cable skidder systems. Forwarders are used to transport short wood or cut-to-length logs clear of the ground, which provides a good solution in the case of longer travelling distances and larger payloads. In recent decades, adapted farming tractors and forest semitrailers have been developed to perform forestry activities (Horvat et al., 2005). Agricultural tractors are cheaper to purchase and operate than purpose-built forest machines, although they cannot achieve such large plans or high outputs (Jones, 1996). Furthermore, the investment level for a tractor-trailer combination is substantially lower than for a conventional forwarder (Russell and Mortimer, 2005). Finally, the tractor-trailer combination should be used as a complement to the main extraction fleet and where hauling operations are required (Spinelli et al., 2004).

The main concern involving forest harvesting operations is probably the danger of lateral rollover and soil damage, which is another significant problem related to harvesting operations. To minimize forest soil damage, forwarding operations are usually suggested.

* Correspondence: giuseppe.digironimo@unina.it

However, forwarders are large vehicles that need to get close to the processed assortments in order to function with a hydraulic crane. Thus, they cannot be employed in situations in which there is a high density stand (Horvat et al., 2005). The tractor-trailer combination can be chosen to move inside the forest without colliding with stand trees or plants.

The main objective of this study was the design of a timber trailer capable of manual loading operations and suitable for rough terrain conditions to be used in combination with an agricultural tractor. The trailer has to be able to do the following: carry logs of specific dimensions for logging extraction operations, secondary transportation, and agricultural activities; ensure the integrity of soil and plants inside the forest area; and avoid rollover in high slope terrain conditions.

2. Materials and methods

2.1. Study area

This study was conducted in the western Black Sea Region (Figure 1), one of the regions of Turkey that is rich in forest resources. Harvesting operations are performed using traditional methods, employing mostly manpower for skidding and tractors for both winching and skidding. The application of advanced mechanized harvesting is limited since harvesting machines are very expensive and they have negative effects on the workforce. The harvesting operations are also limited due to rocky, rough, and steep terrain where ground slope ranges from 30% to 60%.

2.2. Determination of customer needs

The first step of the process, illustrated in Figure 2, is the collection of the most important customer needs through a questionnaire based on the Likert scale. The Likert questionnaire is composed of several statements, each of which the respondent has to assign a value corresponding to his level of agreement, so that is possible to categorize the customer requirements based on the importance given by the respondents (Shneiderman, 1998). The survey provides a better understanding of what customers want and helps the designer to focus on the most important product attributes to be improved (Gustafsson et al., 1999; Cormican and O'Sullivan, 2004; Kuo, 2004; Chen and Su, 2006; Kumar et al., 2006). The first step of the study was the identification of a set of needs related to forestry operations involving a tractor-trailer combination. The list of requirements was developed starting with interviewing experts in the field. The topics included driving ability in difficult terrain conditions, reduced damage to the environment, trailer adaptability to different payloads and operations, and ergonomic operations. The questionnaire was submitted to a group of 21 people involved in forestry activities, composed of forest engineers, whose activities are associated with timber harvesting, timber transport, and road construction; forest rangers, who enforce laws in the forest and oversee preservation of the environment; and the forest workers, who are the people directly involved in the harvesting operations. Every person evaluated a set of 14 statements choosing their degree of adherence to each statement, using a 5-point scale composed in this way: (1) strongly disagree; (2) disagree; (3) undecided; (4) agree; (5) strongly agree.

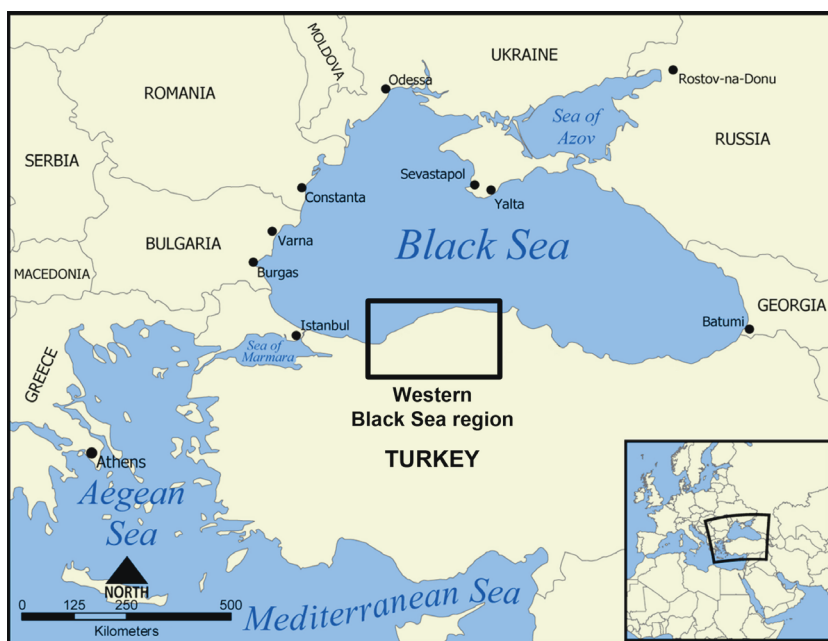


Figure 1. Map of the study area.

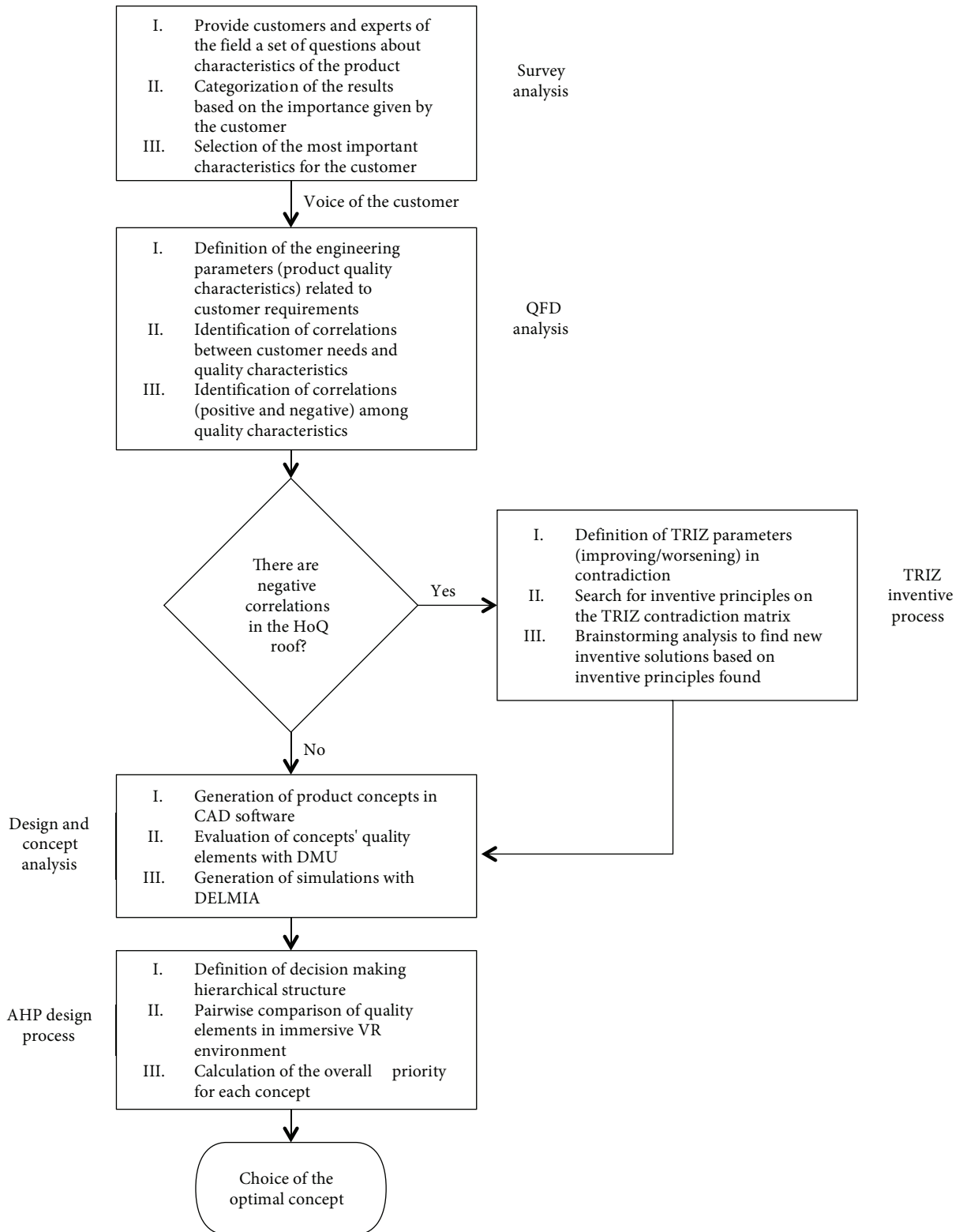


Figure 2. Method flowchart.

2.3. Identification of quality characteristics and conflicts

In order to translate information given by customers into functional requirements, a House of Quality (HoQ) was used, and in particular the study focused onto the top part where the "HOWs" are located, meaning the translation of every customer need into one or more global quality characteristics (Sorensen et al., 2010; Yeh et al., 2010). Customer needs found after the survey analysis were inserted into the left column of the HoQ, because generally customer needs are reproduced in the customers' own words (Hauser and Clausing, 1988). A set of measurable quality characteristics of the product was used to translate the selected customer needs into functional requirements to be designed. Each engineering parameter affects one or more customer attributes, and is inserted in the top row of the HoQ. The next step was the identification of correlations between the various quality characteristics, with an evaluation of the degree of relationship inside the main matrix of the HoQ. In the body of the matrix, the relationship matrix indicates how much each engineering characteristic affects each customer attribute. On the roof matrix of the HoQ, correlations between functional requirements, particularly negative ones, identified which parameters are mutually affected by making changes.

2.4. Determination of inventive solutions

Negative correlations between engineering characteristics, when found in the roof of an HoQ, are solved with the theory of inventive problem solving (TRIZ) contradiction toolkit (Terninko et al., 1998). TRIZ is an engineering problem solving toolkit to systematically solve technical problems. With TRIZ, it is possible to save time, because the instrument lets the engineer head straight for the valid solutions to the problem and then develop those solutions (Gadd, 2011). Several recent papers have shown interesting applications of TRIZ theory, in combination with other tools, to solve technical contradictions (Xinjun, 2003; Wu, 2004; Conradie and Consultores, 2005; Jiangnan and Shixiong, 2011). Adding TRIZ to quality function deployment (QFD) can lead to significant improvements in the innovation of both product and process (Terninko et al., 1998). Each negative correlation found in the roof of the HoQ is composed of 2 quality characteristics in conflict. These characteristics are translated into 2 TRIZ parameters, one improving and the other worsening. The intersection of improving/worsening parameters in the TRIZ contradiction matrix provides a set of inventive principles that guide the inventive process.

2.5. Concept design in virtual reality

Inventive solutions provided by TRIZ analysis generate several product variants that can be designed in parametric CAD software using a top-down modeling approach. The top-down logic is a typical approach to designing a complex product, as stated by many authors (Lee and Gossard, 1985;

Mantripragada and Whitney, 1998; Whitney et al., 1999; Whitney, 2004; Di Gironimo and Patalano, 2008). Adopting a top-down approach, the designer has a complete view of the whole assembly, and it is possible to make considerations and adjustments of the entire assembly in real time, saving time (Di Gironimo et al., 2012b).

2.6. Ergonomic analysis and evaluation of concept characteristics

Once product concepts are designed, a quantitative evaluation is made using digital mock-up (DMU) and ergonomic CAD tools in combination with process simulation software (Di Gironimo et al., 2009b). A set of parameters related to quality elements considered in the HoQ is evaluated. For the evaluation of the interaction with people, the use of manikins is necessary. Recent studies have shown some advantages of using manikins in a virtual environment and for the simulation of human tasks (Di Gironimo et al., 2012a; Di Gironimo et al., 2012d).

2.7. Selection of the best concept in a virtual environment

After the evaluation of product concepts using quality characteristics, a second qualitative evaluation is made by a group of experts to provide their opinion about the importance of each parameter, in order to achieve a quality classification for the product variants. The instrument chosen was the analytic hierarchy process (AHP) (Saaty, 1990). Participative design is important to improve quality not only in applications with industrial backgrounds, but also for nonindustrial ones (Bruno and Muzzupappa, 2010; Yusuf et al., 2011; Di Gironimo et al., 2012c). The purpose of the participative approach is to involve a group of experts to compare several alternative design solutions in order to find an optimal one with the help of an immersive virtual reality (VR) environment (Lanzotti et al., 2009). The immersion in a virtual environment is important to let the expert make both an aesthetic evaluation of the concept and a functional evaluation of all the mechanisms (Di Gironimo and Lanzotti, 2009). With the help of virtual reality, it is possible to perform an interaction with the product and have a live experience of product use (Di Gironimo et al., 2009a; Di Gironimo et al., 2009b). The entire methodology is aimed at producing an optimal concept that satisfies customer requirements and adopts innovative solutions (Di Gironimo et al., 2006). The identification of the optimal concept ends the concept design process.

3. Results

After the survey analysis, in which a mean score for each sentence was calculated, a set of requirements with a score of 4 or greater was obtained (Table 1). The HoQ was then used to find quality characteristics to be designed that reflect the customer needs. The completed HoQ is shown in Figure 3.

Table 1. The most important customer needs.

Mean score	Customer needs
4.76	Side doors must be suitable for manual loading operations
4.72	Damage to remaining stand trees should be prevented
4.49	Trailer must be dedicated not only to timber transportation, but also to other agricultural and forestry operations
4.46	Lateral rollover is important
4.03	Damage to plants on trailer route should be prevented
4.02	Soil damage by tire effect must be prevented
4.00	Trailer must be suitable for transportation of timber of 1–3 m in length

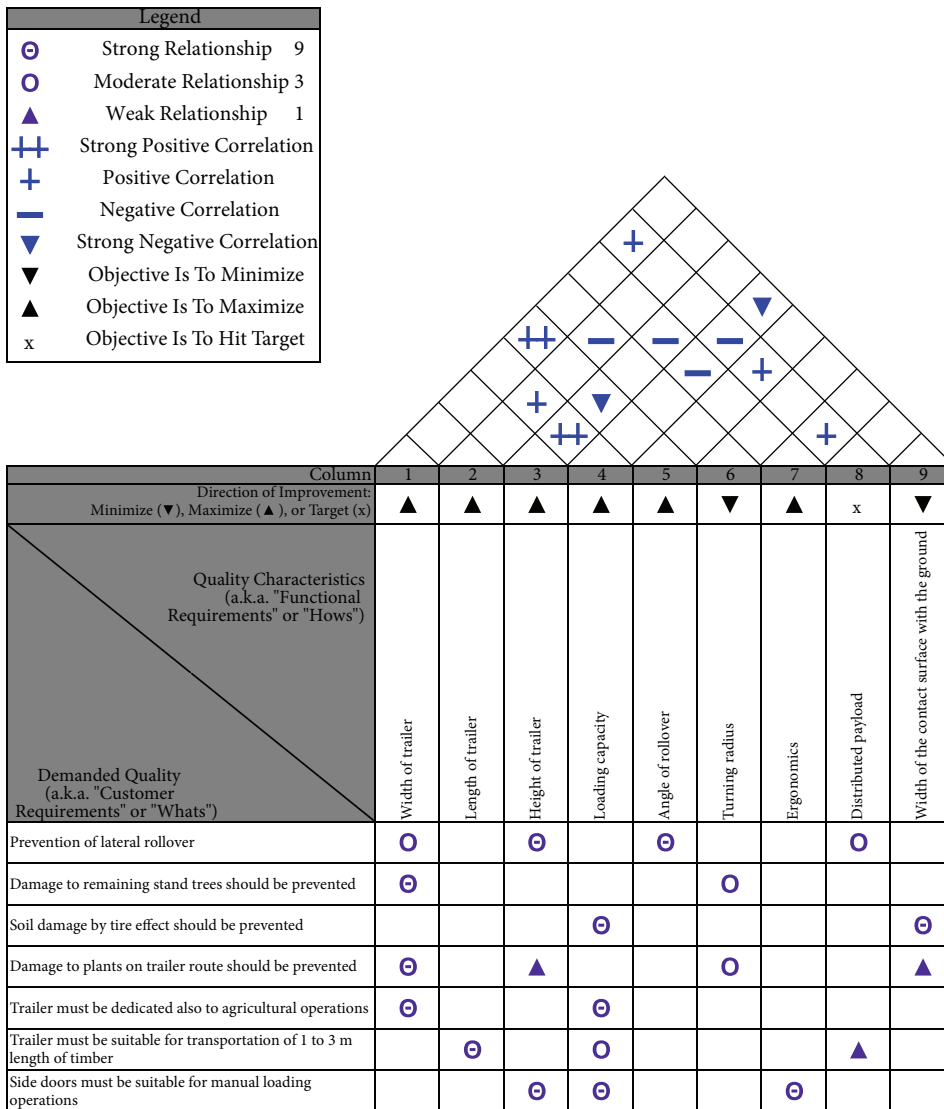


Figure 3. House of Quality diagram.

A set of quality characteristics (or functional requirements) of the product was identified to satisfy those needs and inserted into the top row of the table. These describe the product in measurable terms and directly affect customer perceptions. For example, one of the main customer requirements reported in Table 1 was “trailer must be dedicated not only to timber transportation, but also to other agricultural and forestry operations”. Once both customer requirements and quality characteristics were identified, the relations between them were recognized and are shown in the middle matrix of the HoQ. In the upper part of the HoQ, also known as the roof, several relationships among quality characteristics were recognized. These relationships were both positive and negative (contradictions); 6 contradictions were identified. For example, a tall trailer is a good solution to prevent accidental impacts with terrain obstacles, but this raises the vertical position of the center of mass, thus widening the angle of rollover and posing a danger.

Instead of finding compromises between quality characteristics in conflict, TRIZ theory is used to solve them. For each conflict, a pair of TRIZ parameters are identified, one that will get worse and another that can be improved based on the conflicting elements between the engineering characteristics. The intersection between improving and worsening parameters in the contradictions matrix gives the TRIZ inventive principles that can be followed in order to find new possible engineering solutions for the product. The use of brainstorming sessions as well as technical knowledge is very useful in this phase, because TRIZ analysis works at a high level of abstraction (Terninko et al., 1998).

Table 2 shows the result of the first TRIZ-related step, with the pairs of TRIZ improving/worsening performances associated with every conflict between quality characteristics, and the inventive principles chosen to find special solutions. TRIZ elements in the contradiction matrix were chosen based on the functions that are in conflict in the system. For example, in the first conflict, the height of trailer and the angle of rollover are involved. As the ground slope increases, the higher center of gravity of the load results in reduced stability of the vehicle. The improved performance is the length of the moving object (3), since the distance from the trailer to the ground is important when the vehicle is moving and needs to avoid obstacles. The parameter that worsens when raising the trailer (and thus generating the conflict) is the angle of rollover, associated with the stability (13) principle. The contradiction matrix gives the following inventive principles: segmentation, antiweight, dynamics, discarding, and recovering. The principle selected is dynamics with its subprinciple c, which is that the adopted solution is to make the height of the trailer manually adjustable using a mechanical system that lets the operator change the distance from the wheels to the bottom of the trailer when the vehicle is not moving. With this solution, it is possible to increase the maximum terrain slope in which the trailer can be used (Figure 4).

In the second conflict, the loading capacity of the trailer is in contradiction with the width of the ground contact surface. The greater the trailer’s weight, the more the pressure is transmitted to the soil. The vehicle should be adaptable to difficult terrain conditions with a small contact surface with the terrain to minimize the

Table 2. Conflicts translated into TRIZ.

No.	Quality characteristic improved	Quality characteristic worsened	TRIZ performance improved	TRIZ performance worsened	Inventive principle chosen
1	Height of trailer	Angle of rollover	(3) Length of moving object	(13) Stability	[15.c] Dynamics
2	Loading capacity	Width of the contact surface with the ground	(3) Length of moving object	(1) Weight of moving object	[15.b], [15.c] Dynamics
3	Turning radius	Length of trailer	(33) Ease of operation	(3) Length of moving object	[1.a] Segmentation
4	Ergonomics	Loading capacity of trailer	(33) Ease of operation	(2) Weight of stationary object	[13.a] The other way round, [25.a] Self-service
5	Height of trailer	Ergonomics	(4) Length of stationary object	(33) Ease of operation	[25.a] Self-service
6	Loading capacity	Distributed payload	(7) Volume of moving object	(13) Stability	[10.b] Preliminary action, [1.c] Segmentation

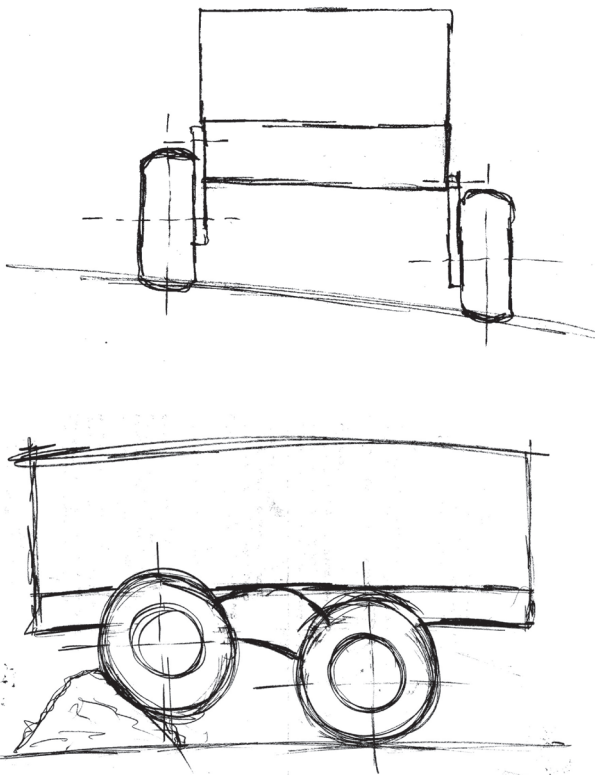


Figure 4. Sketches of the adjustable height function and the tandem wheels design.

probability of hitting an obstacle. The TRIZ improving parameter is the length of the moving object (3) while the worsening parameter is the weight of the moving object (1). The inventive principles found are antiweight, dynamics, pneumatics and hydraulics, discarding, and recovering. The principle selected is dynamics with its subprinciple b, which is that the adopted solution is a

tandem wheel design. The vehicle has 2 wheels per side, but positioned one behind the other and capable of relative movement to each other (4 wheels with 1 axle system) in order to minimize the contact width and also give greater adaptability to different terrain conditions.

Each inventive solution found in the TRIZ analysis (Table 3) was translated into a practical implementation inside the virtual environment. Four concepts were then generated in a CAD environment from the combination of various chassis configurations (Figure 5).

The trailers differ in chassis shape, with 2 different configurations: one is C-shaped and the other is V-shaped. Moreover, the chassis can be of a short type or long type. The difference in the trailer's shape is mainly related to the stability of the vehicle. For example, with the V-shape chassis it is possible to improve the rollover angle without increasing the track width, as shown in Figure 6.

The choice of chassis length is mainly related to the payload capacity for agricultural use. The concepts were then evaluated based on several quality characteristics illustrated in Table 4.

The final evaluation phase of the best concept was carried out through an interactive design approach in the VR lab of the University of Naples Federico II, named "IDEAinVR" (Interactive Design and Ergonomics Simulations in Virtual Reality) (Figure 7).

It involved the participation of 7 experts in order to give weight to every quality characteristic and simulation of trailer operations considered in this step, and to obtain an overall evaluation of each concept. The use of a multi-screen projection system helped the evaluation phase by providing an opportunity to compare 2 different solutions in real time.

The instrument chosen for the decision-making process was the AHP. In the first step of the process, the trailer selection problem was broken down into several

Table 3. TRIZ special solutions and technical solutions adopted.

No	Inventive principle	TRIZ solution	Technical solution(s) adopted
1	[15.c] Dynamics	Adjustable height of trailer	Adjustable height of the wheels using a hydraulic system
2	[15.b], [15.c] Dynamics	4 wheels (1 axle system)	Tandem wheel design
3	[1.a] Segmentation	Articulated drawbar	Removable drawbar with 2 joints (tractor and trailer)
4	[13.a] The other way round, [25.a] Self-service	Symmetrical trailer; turnable trailer	Sliding drawbar or sliding chassis; front drawbar wheel
5	[25.a] Self-service	Extendable side doors; chassis tilt system	Extendable supports inside the doors; hydraulic system to tilt the chassis
6	[10.b] Preliminary action, [1.c] Segmentation	Logs containment system	Adjustable height of logs supports when the chassis is closed; V-shaped chassis

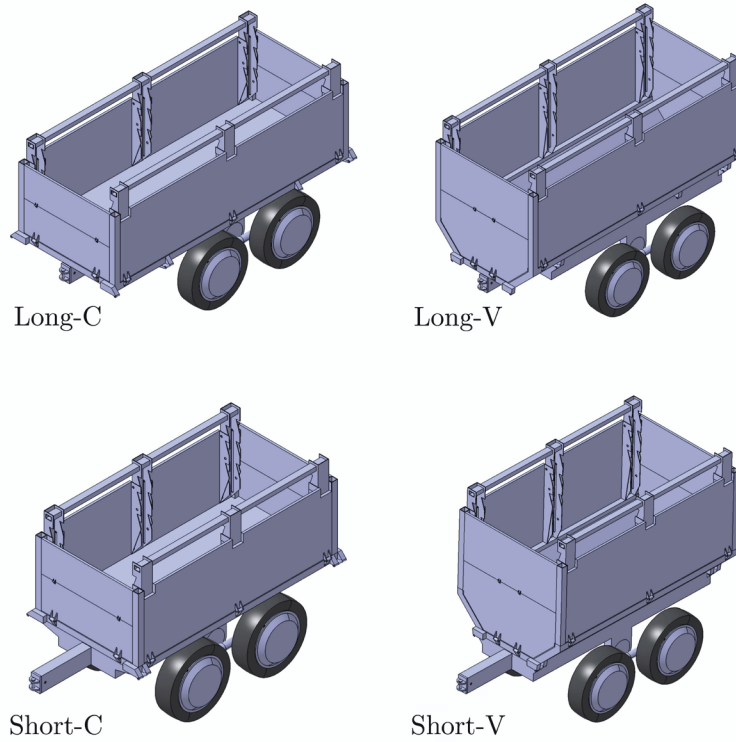


Figure 5. Concepts generated in VR.

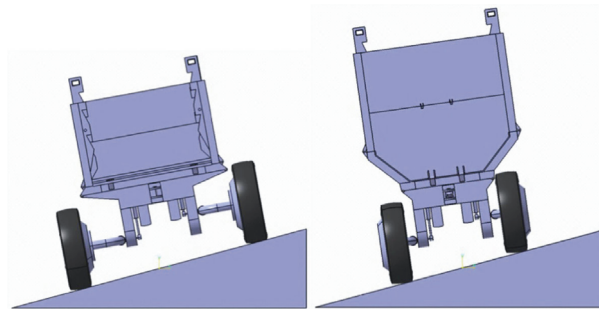


Figure 6. Position of the trailer on sloped terrain with 2 chassis configurations.

Table 4. Summary of quality characteristics evaluation.

Quality element	Score			
	Short-C	Short-V	Long-C	Long-V
Mass, 10 ³ kg	2.70	3.14	3.02	3.54
Max payload (logs), m ³	2.33	3.93	2.33	3.93
Max payload (chassis filled), m ³	2.68	3.36	4.29	5.38
Angle of rollover, °	26.9	28.2	26.3	27.2
Angle of rollover (reversed wheels), °	42.6	38.4	41.9	37.1
Door reachability, % of population	90	10	90	10
Lower back analysis, N	2597	2958	2597	2958



Figure 7. Evaluation phase in the VR lab.

levels identifying a set of criteria and subcriteria (Di Gironimo et al., 2012c). In the first (top) level was the overall goal of trailer choice. In the second level there were 6 criteria that contributed to the goal: mass, loading capacity, angle of rollover, ergonomics, change of trailer direction, and tandem behavior. The third level was composed of subcriteria, which were loading capacity (in terms of logs and full chassis volume), angle of rollover (with normal and reversed wheels), and 3 characteristics related to ergonomics: the reachability of the side door,

the lower back analysis, and the loading operation. In the fourth level (bottom) there are the 4 trailer candidates. All the criteria and subcriteria were analyzed through the previous step with regard to the 4 trailers with an objective evaluation, except for the loading operation, the change of the trailer's direction, and the tandem behavior, all of which require a subjective evaluation by experts. In order to support the decision process, all evaluation activity was carried out in an immersive VR using virtual prototypes and ergonomic simulations realized in DELMIA, as previously done by Di Gironimo and Patalano (2008) and Lanzotti et al. (2009). Figure 8 shows, as an example, the loading operation simulated using virtual manikins.

4. Discussion

According to the survey analysis results shown in Table 1, a set of requirements were collected in order to identify the most important quality characteristics of the product using an HoQ diagram (illustrated in Figure 3). For example, ergonomic operations and the prevention of environmental damage were found to be important. Several studies integrate QFD with TRIZ (Yamashina et al., 2002; Su and Lin, 2007; Lin et al., 2011), which enables the effective and systematic creation of new product functions. With QFD, it is possible to pursue customer satisfaction by developing better products, and the expected outcomes of product development make it profitable to invest in the methodology (Lager, 2005). When system complexity

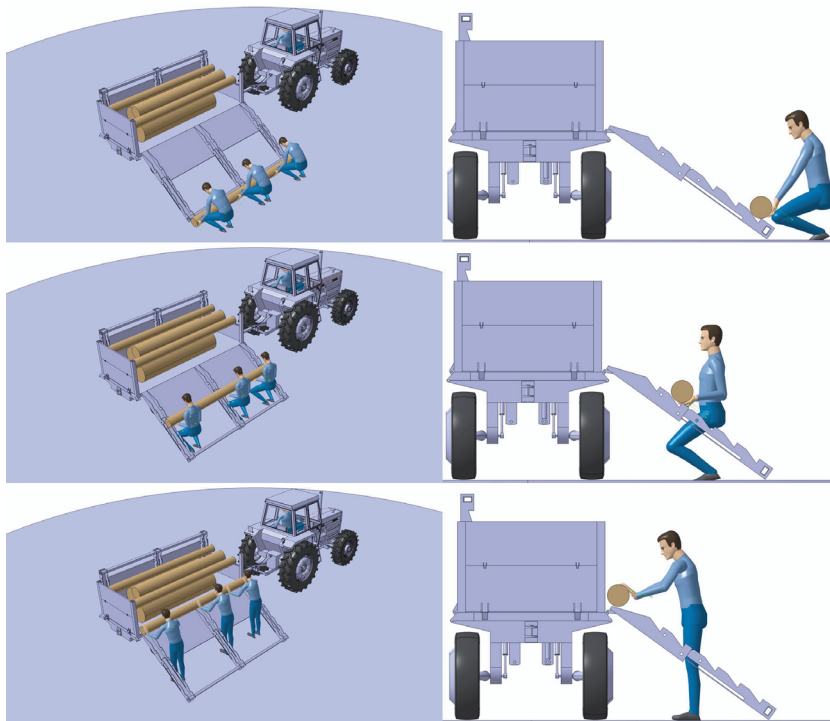


Figure 8. Lower back analysis performed for the loading operation.

increases, QFD shows some deficiencies, which can be overcome by adopting specific remedies (Hari et al., 2007) or adopting different methods specifically designed to handle trade-offs (Dereli and Altun, 2012; Altun et al., 2013). Another important requirement was the combined use in forestry and agricultural operations. Many farm tractors can already be adapted for forest use and some of them are purpose-made for both farm and forestry applications (Russell and Mortimer, 2005), even if these are quite expensive solutions.

Managing the conflicts found in the HoQ with TRIZ, several solutions were found. The adjustable height function provides more stability for the vehicle. When the ground slope increases, a lower center of gravity results in higher stability, in accordance with Akay et al. (2004). Moreover, the tandem solution for the wheels reduces soil damage compared with a traditional 2-wheel, single-axle trailer that causes more ground damage and is affected by rough terrain (Jones, 1996).

In Table 5, the final rankings of the alternatives are given against the covering criteria and subcriteria. To get the final priority for a concept, it is necessary to multiply each ranking by the priority of its criterion or subcriterion and add the resulting weights for each alternative (Saaty, 2008). The alternative with the highest score is the Short-C trailer, with a weight of 34%. The final concept (Figure 9) has a total length of 3.35 m, a width of 1.34 m, and a height of 1.8 m (door upper limit).

Farm tractor logging can be limited by some factors including terrain conditions, ground slope, and timber size (Akay, 2005). The selected concept, thanks to the combination of a low center of mass, a tandem design for

the wheels, and the possibility to adopt a reversed wheel configuration, ensures very high stability in conditions of rough terrain and slopes ranging from 30% to 60%, representing a flexible solution for timber harvesting operations in Turkey.

The “C” chassis configuration, being lower than the “V” one, ensures more ergonomic loading/unloading operations, because the upper ends of the trailer’s side doors are easily reachable by the majority of the population. Furthermore, when the side doors are opened with the loading supports in the extended position, the workers have to support less weight while pushing the logs inside the chassis. This is shown by a reduced lower back pain evaluation performed on virtual manikins. A trailer with side doors will take less time to unload than one without side doors, and can therefore make more trips per day over a given haulage distance (Hamper and Mason, 1997).

Moreover, the Short-C trailer is the smallest between the various alternatives; thus its mass is the lowest. This has a positive effect with respect to the preservation of soil integrity; a lighter vehicle means less pressure transmitted to the ground by the wheels. On the other hand, the Short-C trailer has a smaller loading capacity with respect to the other solutions. However, this is compatible with its main use in primary transportation activities, where loading volumes are also small. Furthermore, the dimensions of the trailer are in accordance with the Turkish legal standards (Kadayıfçılar, 1993). Reduced dimensions are a benefit also with respect to maneuverability, particularly in conditions where the density of the stand is high. Forwarders are large vehicles; for this reason they cannot be used in areas where there is a high stand density (Horvat et al., 2005).

Table 5. Final results of the AHP evaluation.

Criteria (weight)	Subcriteria	Global weights	Short-C	Short-V	Long-C	Long-V
Mass		0.13	0.20	0.54	0.18	0.08
Loading capacity (0.07)	Loading capacity (logs)	0.07	0.07	0.28	0.11	0.54
	Loading capacity (full chassis)	0.04	0.05	0.10	0.22	0.62
Angle of rollover (0.26)	Normal wheels	0.07	0.15	0.51	0.11	0.22
	Reversed wheels	0.19	0.54	0.14	0.22	0.11
Ergonomics (0.22)	Reachability of the side door	0.04	0.49	0.08	0.36	0.07
	Lower back analysis	0.08	0.38	0.12	0.38	0.12
	Loading operation	0.09	0.38	0.06	0.44	0.12
Change of trailer direction		0.11	0.44	0.34	0.13	0.09
Tandem behavior		0.17	0.08	0.37	0.11	0.44
Overall priority			0.34	0.23	0.21	0.22

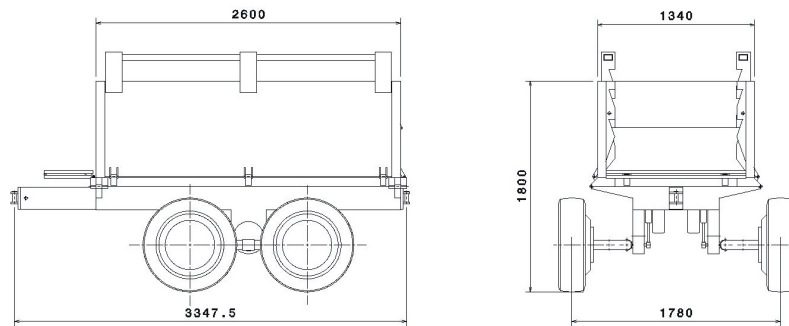


Figure 9. Dimensions of the final trailer concept (with wheels reversed).

The tractor–trailer combination is designed to be able to move inside the forest without colliding with stand trees or plants according to safety recommendations in wood harvesting (Engür, 2011).

In the above discussion, the concept design of a timber trailer for use in forestry harvesting and agricultural operations was realized for further engineering development phases. The vehicle is capable of manual loading operations and is suitable for rough terrain conditions. In particular, the chosen concept is capable of movement in terrains with slopes ranging from 30% to 60% and with the presence of obstacles, allowing for more productivity among high density stand trees, ergonomic loading operations, and reduced environmental damage to soil and vegetation. The final concept has a mass of 2700 kg, a payload capacity of about 2.33 m³ (logs), and a total chassis volume of 2.68 m³. The angle of rollover is 26.9°, the door is reachable by 90% of the population, and the lower back analysis performed for the loading operation showed a maximum value of 2597 N.

While the combined use of QFD and TRIZ has been reported in the literature, the proposed use of VR and

AHP seems to be innovative in the evaluation phase. In particular, VR improves the interaction of the experts with the virtual concepts, allowing an adequate subjective evaluation. AHP allows not only evaluation of the weights of the different concepts, but also prioritization of the different quality elements.

The final concept chosen seems to be suitable for the Turkish forests, flexible enough for agricultural use, and cheap. As a continuation to this study, a comparison could be made with existing and more expensive trailers dedicated to harvesting operations.

Acknowledgements

The present work was developed with contributions by the Scientific and Technological Research Council of Turkey (TÜBİTAK), the Italian Ministry of Education, University and Research (MIUR) within the framework of the project “Digital Pattern Product Development”, and Regione Campania within the framework of the projects INSIST and “Dottorato in Azienda”. The authors also thank Rocco Mozzillo and Fabrizio Renno for their technical support.

References

- Akay AE (2005). Using farm tractors in small-scale forest harvesting operations. *J Appl Sci Res* 1: 196–199.
- Akay AE, Erdas O, Sessions J (2004). Determining productivity of mechanized harvesting machines. *J Appl Sci* 4: 100–105.
- Altun K, Dereli T, Baykasoğlu A (2013). Development of a framework for customer co-creation in NPD through multi-issue negotiation with issue trade-offs. *Expert Syst Appl* 40: 873–880.
- Bruno F, Muzzupappa M (2010). Product interface design: a participatory approach based on virtual reality. *Int J Hum Comp St* 68: 254–269.
- Chen YH and Su CT (2006). A Kano-CKM model for customer knowledge discovery. *Total Qual Manage* 17: 589–608.
- Conradie I, Consultores I (2005). TOC and TRIZ: Using a dual-methodological approach to solve a forest harvesting problem. *TRIZ J March*: 1–10.
- Cormican K, O’Sullivan D (2004). Auditing best practice for effective product innovation management. *Technovation* 24: 819–829.
- Dereli T, Altun K (2012). Modified even-swaps: a novel, clear, rational and an easy-to-use mechanism for multi-issue negotiation. *Comput Ind Eng* 63: 1013–1029.
- Di Gironimo G, Di Martino C, Lanzotti A, Marzano A, Russo G (2012a). Improving MTM-UAS to predetermine automotive maintenance times. *Int J Interact Des Manuf* 6: 265–273.

- Di Gironimo G, Franciosa P, Gerbino S (2009a). A RE-CAE methodology for re-designing free shape objects interactively. *Int J Interact Des Manuf* 3: 273–283.
- Di Gironimo G, Lanzotti A (2009). Designing in VR. *Int J Interact Des Manuf* 3: 51–53.
- Di Gironimo G, Lanzotti A, Melemez K, Renno F (2012b). A top-down modeling based approach for the virtual redesign and the ergonomic optimization of an agricultural tractor's driver cab. ASME 11th Biennial Conference on Engineering Systems Design and Analysis, Nantes, France.
- Di Gironimo G, Lanzotti A, Vanacore A (2006). Concept design for quality in virtual environment. *Comput Graph* 30: 1011–1019.
- Di Gironimo G, Matrone G, Tarallo A, Trotta M, Lanzotti A (2012c). A virtual reality approach for usability assessment: case study on a wheelchair-mounted robot manipulator. *Eng Comput* 29: 359–373.
- Di Gironimo G, Patalano S (2008). Re-design of a railway locomotive in virtual environment for ergonomic requirements. *Int J Interact Des Manuf* 2: 47–57.
- Di Gironimo G, Patalano S, Tarallo A (2009b). Innovative assembly process for modular train and feasibility analysis in virtual environment. *Int J Interact Des Manuf* 3: 93–101.
- Di Gironimo G, Pelliccia L, Siciliano B and Tarallo A (2012d). Biomechanically-based motion control for a digital human. *Int J Interact Des Manuf* 6: 1–13.
- Engür MO (2011). *Odun Üretiminde Çalışanlar için El Kitabı*. Bolu, Turkey: Bolu Orman Bölge Müdürlüğü (in Turkish).
- Gadd K (2011). *TRIZ For Engineers: Enabling Inventive Problem Solving*. Sussex, UK: John Wiley & Sons, Ltd.
- Gustafsson A, Ekdahl F, Edvardsson B (1999). Customer focused service development in practice: a case study at Scandinavian Airlines System (SAS). *Int J Serv Ind Manag* 10: 344–358.
- Hamper J, Mason D (1997). *Designs and Specifications for a Standard Trailer and Hitch for Labour-based Works*. International Labour Organization, Advisory Support Information Services and Training (ILO/ASIST).
- Hari A, Kasser JE, Weiss MP (2007). How lessons learned from using QFD led to the evolution of a process for creating quality requirements for complex systems. *Sys Eng* 10: 45–63.
- Hauser JR, Clausing D (1988). The house of quality. *Harvard Bus Rev* May–June: 63–73.
- Horvat D, Spinelli R, Susnjar M (2005). Resistance coefficients on ground-based winching of timber. *Croat J For Eng* 29: 3–11.
- Jiangnan L, Shixiong Z (2011). Study on vehicle-mounted snow-remover & deicer for trees based on TRIZ. Proceedings of the International Conference on Electric Information and Control Engineering, 15–17 April 2011, Wuhan, China.
- Jones DH (1996). *The Adaptation of Agricultural Tractors for Forestry*. UK Forestry Commission, Forest Research, Technical Development Branch, Technical Note 24/95.
- Kadayıfçılar S (1993). *Traktör Arabalarının Tasarım Esasları*. Ankara, Turkey: University of Ankara Agriculture Faculty Publications 1297, Book 373.
- Kumar V, Venkatesan R, Reinartz W (2006). Knowing what to sell, when, and to whom. *Harvard Bus Rev* 8: 131–137.
- Kuo YF (2004). Integrating Kano's model into web-community service quality. *Total Qual Manag* 15: 925–939.
- Lager T (2005). The industrial usability of quality function deployment: a literature review and synthesis on a meta-level. *R&D Manag* 35: 409–426.
- Lanzotti A, Di Gironimo G, Matrone G, Patalano S, Renno F (2009). Virtual concepts and experiments to improve quality of train interiors. *Int J Interact Des Manuf* 3: 65–79.
- Lee K, Gossard D (1985). A hierarchical data structure for representing assemblies. *CAD* 17: 15–19.
- Lin CS, Chen LS, Hsu CC (2011). An innovative approach for RFID product functions development. *Expert Syst Appl* 38: 15523–15533.
- Mantripragada R, Whitney D (1998). The datum flow chain: a systematic approach to assembly design and modeling. *Res Eng Des* 10: 150–165.
- Öztürk T (2010). Productivity of New Holland farm tractor at beech stands on mountainous areas in Black Sea region. *For Ideas* 16: 52–57.
- Russell F, Mortimer D (2005). *A Review of Small-scale Harvesting Systems in Use Worldwide and their Potential Application in Irish Forestry*. Dublin, Ireland: COFORD, National Council for Forest Research and Development.
- Saaty TL (1990). How to make a decision: the analytic hierarchy process. *Eur J Oper Res* 48: 9–26.
- Saaty TL (2008). Decision making with the analytic hierarchy process. *Int J Serv Sci* 1: 83–98.
- Sabo A, Porsinsky T (2005). Skidding of fir roundwood by timberjack 240c from selective forests of Gorski Kotar. *Croat J For Eng* 26: 13–27.
- Shneiderman B (1998). *Designing the User Interface: Strategies for Effective Human-Computer Interaction*. 3rd ed. Reading, MA, USA: Addison Wesley Longman, Inc.
- Sorensen CG, Jorgensen RN, Maagard J, Bertelsen KK, Dalgaard L, Norremark M (2010). Conceptual and user-centric design guidelines for a plant nursing robot. *Biosyst Eng* 105: 119–129.
- Spinelli R, Owende MO, Ward SM, Tornero M (2004). Comparison of short-wood forwarding systems used in Iberia. *Silva Fenn* 38: 85–94.
- Su CT, Lin CS (2007). A case study on the application of fuzzy QFD in TRIZ for service quality improvement. *Qual Quant* 42: 563–578.
- Terninko J, Zusman A, Zlotin B (1998). *Systematic Innovation: An Introduction to TRIZ (Theory of Inventive Problem Solving)*. Boca Raton, FL, USA: CRC Press.

- Tunay M (2006). The assessment of environmentally sensitive forest road construction in calabrian pine forest areas of Turkey. *J Environ Biol* 27: 529–535.
- Whitney D (2004). *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY, USA: Oxford University Press.
- Whitney D, Mantripragada R, Adams J, Rhee S (1999). Designing assemblies. *Res Eng Des* 11: 228–253.
- Wu TD (2004). The study of problem solving by TRIZ and Taguchi methodology in automobile muffler designation. *TRIZ J* March: 1–21.
- Xinjun Z (2003). Develop new kind of plough by using TRIZ and robust design. *TRIZ J* June: 1–5.
- Yamashina H, Ito T, Kawada H (2002). Innovative product development process by integrating QFD and TRIZ. *Int J Prod Res* 40: 1031–1050.
- Yeh CH, Huang JCY, Yu CK (2010). Integration of four-phase QFD and TRIZ in product R&D: a notebook case study. *Res Eng Des* 22: 125–141.
- Yusuf S, Georgakis P, Nwagboso C (2011). Procedural lot generation for evolutionary urban layout optimization in urban regeneration decision support. *Electron J Inform Tech Constr* 16: 357–380.