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A subjective framework for seat comfort based on a heuristic multi criteria decision making technique and anthropometry

Hamed Fazlollahtabar

Department of Industrial Engineering, Mazandaran University of Science and Technology, Babol, Iran

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ABSTRACT

Consumer expectations for automobile seat comfort continue to rise. With this said, it is evident that the current automobile seat comfort development process, which is only sporadically successful, needs to change. In this context, there has been growing recognition of the need for establishing theoretical and methodological automobile seat comfort. On the other hand, seat producer need to know the costumer's required comfort to produce based on their interests. The current research methodologies apply qualitative approaches due to anthropometric specifications. The most significant weakness of these approaches is the inexact extracted inferences. Despite the qualitative nature of the consumer's preferences there are some methods to transform the qualitative parameters into numerical value which could help seat producer to improve or enhance their products. Nonetheless this approach would help the automobile manufacturer to provide their seats from the best producer regarding to the consumers idea. In this paper, a heuristic multi criteria decision making technique is applied to make consumers preferences in the numeric value. This Technique is combination of Analytical Hierarchy Procedure (AHP), Entropy method, and Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). A case study is conducted to illustrate the applicability and the effectiveness of the proposed heuristic approach.

1. Introduction

Automobile seat comfort, which has been worked out with a background in ergonomics, has developed as an applied science. Traditional research in this area has been motivated by: (1) a practical concern for the health and well-being of the consumer and (2) the view that comfort is a product differentiator in the eyes of the end consumer. However, the discipline has a tendency to be reactive to current needs, rather than proactive, and has often borrowed ideas and approaches from other fields (i.e. engineering and psychology). As a result, there has been little emphasis on nurturing theories and methods unique to automobile seat comfort.

In general seat comfort has been investigated in different vehicles. In the field of office chair comfort some studies have been worked out to investigate the effect of highly adjustable chair on office workers' knowledge and musculoskeletal risks (Robertson et al., 2009). Another study has been performed to compare office chair versus sitting on an exercise ball. The study analyzed the affect of static and dynamic aspects of working posture (Kingma and van Dieën, 2009). In a study the influence of chair characteristics on comfort, discomfort, adjustment time and seat interface pressure was investigated. The two investigated office chairs, both designed according to European and Dutch standards are different regarding: 1) seat cushioning and shape, 2) backrest angle and 3) controls (Groenesteijn et al., 2009).

The effect of seat pressure in bicycle has been investigated by Bressel et al. (2009). Thirty participants, comprising male and female cyclists, pedaled a bicycle at 118 W over a 350 m flat course under three different seat conditions: standard seat, a seat with a partial anterior cutout, and a seat with a complete anterior cutout. The pressure between the bicycle seat and perineum of the cyclist was collected with a remote pressure-sensing mat, and perceived stability was assessed using a continuous visual analogue scale. The effect of vertical vibration of steering wheels on comfort has been studied by Morioka and Griffin (2009).

In a study the authors determined the influence of different cover and cushion materials on the thermal comfort of aeroplane seats. Different materials as well as ready made seats were investigated by the physiological laboratory test methods Skin Model and seat comfort tester. Additionally, seat trials with human test subjects were performed in a climatic chamber (Bartels, 2003).

E-mail address: hamed@ustmb.ac.ir

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There has been growing recognition of the need for automobile seat comfort research to establish a theoretical and methodological foundation, so as to achieve recognition as a more legitimate scientific discipline and to enable its further development. Unfortunately, seat comfort researchers are often uncomfortable theorizing (i.e. integrating groups of fundamental principles that underlie a science), yet theory is universally understood to be an essential underpinning for any discipline that aspires to be perceived as a true science. The present contribution hopes to stimulate and lead the development of a theoretical basis for the science of automobile seat comfort and to formulate a methodology for this discipline.

The ergonomics of seat comfort has been studied from a number of different perspectives (Zhang et al., 1996; Yamazaki, 1992). As a generalization, the current practice is to design automobile seats to satisfy ergonomics criteria (synonymous with ergonomics guidelines).This approach is assumed to translate into positive consumer comfort ratings. For the purposes of this paper, there are two categories of ergonomics criteria. They are physiological and anthropometric.

1.1. Physiological ergonomics criteria

The physiological factors, which deal with muscles, vertebral discs, joints, and skin, have traditionally been quantified using electromyography (Bush et al., 1995; Lee and Ferraiuolo, 1993; Sheridan et al., 1991), disc pressure measurement (Andersson et al., 1974), vibration transmissibility (Ebe and Griffin, 2000), pressure distribution at the occupant–seat interface (Kamijo et al., 1982; Hertzberg, 1972), and microclimate at the occupant–seat interface (Diebschlag et al., 1988).

Ergonomics criteria related to physiology have, however, come under scrutiny, particularly in the past decade. Reed et al. (1991a,b), for example, described the automobile seat designer's dilemma as the need for a balance between prescribing a physiologically appropriate seated posture and accommodating a driver in a preferred posture. They reasoned that prescribed postures sometimes compromise long-term comfort. Later, Reed et al. (1995), based on their preliminary data, highlighted the incompatibility between the traditional practice of designing automobile seatbacks to induce a large degree of lumbar lordosis (which is, according to Andersson et al., 1974, appropriate from a physiological perspective) and the ideal of satisfying occupant-selected spinal configurations (which, for some occupants, are more kyphotic). Reed and Schneider (1996) verified this incompatibility in a follow-up study. Kolich et al. (2000a,b), in the context of their investigation, came to a similar conclusion. These investigations all suggest that the human body has a great plasticity to adapt to a large variety of sitting conditions. For this reason, ergonomics criteria based on physiology, because they do not ensure comfort, may unnecessarily limit automobile seat design.

1.2. Anthropometric ergonomics criteria

Due in large part to Akerblom's (1948) work, ergonomics criteria related to anthropometry have long been considered a key aspect of comfortable seating. From this perspective, designers must ensure that a range of people, from small to large, fit in the seat. In general, automobile seat designs are specified by noting, for a target population, the constraining values of appropriate anthropometric dimensions (usually 5th percentile female and 95th percentile male).

Comfortable accommodation in the lumbar region is best achieved through adjustability. This is, in the context of most applications, often impractical, due to the associated cost. According to Reed et al. (1994), the apex of the lumbar contour should be positioned between 105 and150 mm from H-Point. As an aside, in the automotive seating industry, many anthropometric dimensions are referenced from H-Point, which is based on the hip point of a manikin that represents how medium-sized men sit in, and interact with, different vehicle seats and vehicle environments (Society of Automotive Engineers, 1995). This aforementioned range is thought to capture the L3 joint level for both small females and large males in the sitting posture. In the upper seatback (at approximately chest height), the minimum width should support the chest breadth of a large male when reclining. The interscye distance, measured across the back between the posterior axillary folds, is an appropriate anthropometric reference measurement. According to Reed et al. (1994), 471 mm should accommodate the 95th percentile male interscye distance. Failure to satisfy this criterion may compromise seatback lateral support. Cushion length is an important determinant of thigh support. A cushion that is too long can put pressure on the posterior portion of the occupant's legs near the knee. Pressure in this area will lead to local discomfort and restricted blood flow to the legs (Reed et al., 1994). Cushion length is constrained by the buttock-to-popliteal length of the 5th percentile female segment of the population. This dimension is measured on the seated occupant from the rearmost projection of the buttocks to the popliteal fold at the back of the knee.

Gordon et al. (1989) reported a 5th percentile female buttock-to-popliteal length of 440 mm. This equates to approximately 305 mm from H-Point. This dimension/criterion is a maximum. In the case of cushion width, the 95th percentile female sitting hip breadth is used as a specification limit, since this measure exceeds the 95th percentile male sitting hip breadth. Using the principle of anthropometric accommodation, the minimum cushion width must be greater than the 95th percentile female sitting hip breadth of 432 mm (Gordon et al., 1989). However, a larger minimum cushion width is required, mainly because the cited anthropometric measurement does not include a margin for clothing (an automobile seat must generally be suitable for use in cold climates where heavy clothing is worn). Reed et al. (1994) believe that automobile seats should provide a clearance of 500 mm at the hips. This characteristic affects cushion lateral support.

1.3. Subjective perceptions of comfort

Subjective perceptions of comfort must be quantified before they can be compared to ergonomics criteria related to anthropometry. In the automotive seating industry, structured surveys are commonly used for this purpose. The lack of emphasis on seat comfort survey design (exceptions include Reed et al., 1991a,b; Shen and Parsons, 1997; Kolich, 1999) is surprising given (1) the extent to which seat comfort development relies on survey data and (2) the fact that many of the problems related to the collection of subjective data have been well known for some time.

The seat has an important role to play in fulfilling comfort expectations. The prevailing school of thought, in the automotive industry, is that the best way to achieve a comfortable seat design is through an iterative, jury evaluation process. Jury evaluations usually involve the administration of highly structured surveys, which direct occupants to assign feelings of discomfort to specific regions of the seat. The nature of the jury evaluation methodology makes it is necessary to investigate the opinions of large groups of occupants in order to determine the impact of various design features on perceived seating comfort (Manenica and Corlett, 1973). This trial-and-error approach is very time consuming, expensive, and prone to measurement error.

From the perspective of providing design direction, seat system design teams struggle with jury evaluations because, while offering credible evaluations in terms of face validity, the output is poor in terms of experimental rigor. This creates a scenario in which prototypes built to address specific comfort issues (i.e., those arising from one set of jury evaluations) fail to produce the expected results in future jury evaluations. That is, design decisions appear suspect /faulty even though they were appropriate given the available data.

The current seat comfort development process is also limited in that it does not directly consider readily available tools, which provide quantitative data. One of the better-developed approaches is based on pressure measurement at the occupant–seat interface (Hertzberg, 1972; Kohara and Sugi, 1972; Chow and Odell, 1978; Kamijo et al., 1982; Diebschlag et al., 1988). The technology relies on thin, flexible tactile sensor arrays and allows for a wide variety of experiments to be conducted in real time without requiring modification to the seat under investigation.

2. Performance measures for automobile seat comfort based on physiology and biomechanics

Many within the automotive seating industry consider the subjective nature of seat comfort as an impediment to design because they understand that consumers will continue to evaluate comfort in very subjective ways and also because they have themselves struggled with the current development process. The common belief is that seat system design teams desperately need objective, measurable laboratory standards that can be linked to subjective perceptions of comfort (i.e. performance measures). Evaluation methods that provide insight into human physiology and biomechanics are, therefore, currently being examined. Recent advances in sensing technologies have allowed for new and improved characterization of the occupant–seat interface (Park and Kim, 1997; Sheridan et al., 1991). The application of these technologies permits a wide variety of experiments to be conducted, in real-time, without requiring modification to the seats under investigation. These technologies will be instrumental in understanding the underlying mechanism of automobile seat comfort, particularly as it relates to physiology and biomechanics.

2.1. Pressure distribution

There is technology, for example, that can be used to assess the pressure distribution at the occupant–seat interface. Some researchers have suggested that pressure distribution affects perceptions of seat comfort (Diebschlag et al., 1988; Hertzberg, 1972; Kamijo et al., 1982; Kohara and Sugi, 1972). This is controversial. What can be said, given the current state of knowledge, is that a good pressure distribution indicates sufficient and balanced support to body areas in contact with the automobile seat.

How to achieve balanced support and what constitutes balanced support is debatable. This topic requires more research.

2.2. Thermal comfort

Thermal comfort, in terms of both temperature and humidity, can be monitored using different types of sensors. A buildup of temperature and humidity at the skin surface can lead to discomfort, partly because of an increase in the coefficient of friction when the skin is moist. Perspiration that is trapped against the skin by the soft trim (foam and fabric) can produce a sticky feeling if the skin is warm, or a clammy feeling if it is cold. The soft trim is thought to be an important determinant of the microclimate. There is little published literature that can be used to design a comfortable microclimate. Nevertheless it is possible to derive generalities (Diebschlag et al., 1988).

For example, (1) body heat and water vapor must be allowed to pass through the seat (i.e. soft trim that substantially impedes heat or water vapor transfer is to be avoided), (2) perforated cover materials are desirable because of reduced resistance to water vapor diffusion, and (3) soft foam should be avoided because it increases the resistance to water vapor diffusion. Even without clear design direction, efforts are now being made to actively control thermal comfort (e.g. seat heaters and ventilation devices). These innovations cannot be optimized without a clear understanding of what constitutes thermal comfort and what factors affect thermal comfort (i.e. performance metrics are required to assess the viability of the product designs).

2.3. Fatigue

Fatigue, as indicated by the electrical activity in contracting muscle (i.e. EMG signals), can also be detected using today's technology. There are advantages and disadvantages to this method. According to Giroux and Lamontagne (1990), surface electrodes (which are the type of electrodes most commonly used for automotive seating studies) are reliable on a day-to-day basis, quick and easy to attach, do not cause discomfort or pain, and have good reproducibility. In terms of disadvantages, the EMG signals are influenced by a specific subject's muscle geometry, diet (glucose levels), variation in sleep patterns, and activity levels preceding the test (Lee et al., 1995). To counter these concerns, the electrodes must be attached to the individual in a way that achieves low electrical impedance. Often this requires clinical-type experimental controls (e.g. shaving hair, removing dry skin cells, and using a biocompatible electrode paste), which may be overly invasive for laboratories commonly found in the automotive seating industry. Other disadvantages include the cumbersome test equipment and data acquisition systems (i.e. electrodes, amplifier, personal computer), the fact that the electrodes may be perceived as annoying and may, therefore, negatively affect perceptions of comfort, and the considerable amount of time it takes to obtain a measurable effect. While some automobile seat comfort researchers are turned off by these limitations, others have continued to use EMG as an objective indicator of fatigue (Kolich et al., 2000a,b, 2001; Bush et al., 1995; Greiff and Guth, 1994; Lee and Ferraiuolo, 1993; Sheridan et al., 1991). Unfortunately, the research has failed to produce standards for acceptable EMG levels. Accelerometers allow researchers to quantify the vibration transmitted through the seat to the occupant.

2.4. Vibration transmissibility

Vibration transmissibility, particularly in the vertical direction, is one of the most studied objective measures of automobile seat comfort, yet the topic is clearly not well understood, as demonstrated by the automotive seating industry's difficulty with vibration control (Kolich et al., 2004). Just as with the other methods, generalities, as opposed to design criteria, can be gleaned from the published literature. Griffin (1994) suggests that occupants, due to the primary flexion mode of the trunk, show a resonance in vertical vibration between 4 and 8 Hz. Vibration transmissibility should, therefore, be minimized in the 4–8 Hz range. This is complicated because occupied vehicle seats tend to produce a resonance in the same range.

2.5. Back pain

The physiology and biomechanics associated with back pain, which Coventry (1968) referred to as a disease of the automotive age, represents another topic that begs to be understood from the perspective of performance metrics. One of the predominant factors associated with back pain is the time spent driving (Kelsey and Hardy, 1975). The risk factor stems from what Grieco (1986) calls postural fixity.

This phenomenon occurs when an individual sits in one position, without significant postural movement, for an extended period of time. In the driving environment, where postures are determined and therefore fixed by the pedals, the steering wheel, the seat belt, the visual demands of the task, and the seat itself, the resulting static loading of the body's musculature has many detrimental effects including the flow of blood (which transports metabolic products) to and from localized areas. Burton et al. (1996) showed that vehicle exposure had a small effect on low back pain while Battie et al. (2002) found that low back pain did not differ between occupational drivers and a control group.

3. The obstacles of seat comfort development

The overwhelming lack of consensus regarding the findings derived from the available performance measures is immediately apparent. This may be due, at least partly, to differences in protocol. Methodological standards are required. This is critical to any scientific discipline; automobile seat comfort is no exception. The lack of standardization has impeded the advancement of a theoretical and methodological basis for automobile seat comfort research. As part of establishing standards, the performance measures must be shown to be reliable and valid, in much the same way as reliability and validity needs to be established for subjective data. Only in this way, will the automotive seating industry be able to quantify comfort in a manner that will allow for different seats to be distinguished.

The lack of methodological standardization is most apparent in terms of subject selection/sampling. A common, although not uniformly applied, practice is to use a subject group that has an equal distribution of small females, medium males, and large males. The rationale is that seats are designed to accommodate the population from small (5th percentile female) to large (95th percentile male). The selection criteria are usually stature and mass.

This is limited in that someone who is 50th percentile in height is not necessarily 50th percentile in hip breadth, seating height, body mass, popliteal length, etc. Another widespread approach is to select subjects that match the anthropometric and demographic characteristics of the target buyers.

Both of the preceding selection strategies may, however, be flawed given selected performance measures. Consider, for example, the fact that some occupants will produce relatively even pressure distributions, even on hard seats, because of ample adipose tissue, while other more lean subjects will produce high-pressure peaks even on a wellpadded seat. Since the former are not likely to experience discomfort because of excessive local pressure, it is reasonable to restrict many pressure distribution investigations to specific subpopulations who are particularly sensitive to changes in stiffness, geometry, and contour; namely, heavy, lean subjects, and small subjects for whom cushion-leg interference is more likely. It is not difficult to envision how the same types of concerns may affect the microclimate at the occupant–seat interface. Different amounts of subcutaneous fat may also affect the EMG signal, particularly when the electrodes are configured to target the lower back musculature. In terms of vibration transmissibility, the structures of the human body are known to vary widely in terms of compliance and damping characteristics (e.g. bones vs. soft tissues). This variance may affect the results. Given these concerns, it may be more valuable for sampling procedures to target worst-case anthropometric characteristics under the assumption that the resulting seat designs are likely to be acceptable to a larger percentage of the population.

Another methodological problem stems from the fact that subjects participating in experimental investigations into pressure distribution, microclimate, EMG, and vibration transmissibility are usually asked to sit in prescribed postures. There is a difference between preferred and prescribed postures (Reed et al., 1995). Therefore, the performance measures obtained from an experiment may not extend to actual driving conditions.

In the end, the methodological standards would, ideally, include instructions on how to reduce the data into meaningful characteristics. It may be useful, for example, to consider pressure (perhaps peak pressure) in specific body regions, along with contact area. Thermal comfort could be assessed using total heat and water vapor transfer at the occupant–seat interface. EMG signals can be analyzed for both amplitude and frequency. This can be done for specific muscle groups. Resonant frequency, resonant amplitude, and isolation frequency can be derived from vibration transmissibility studies. Sensitivity analyses could be conducted with a standard set of performance measures to determine the difference required to affect subjective perceptions of comfort (this is another area in which reliable and valid questionnaires will be required).

With standard method for pressure distribution, thermal comfort, muscle fatigue, and vibration transmissibility it would be possible for any researcher, scientist, or engineer anywhere in the world to compare seat designs and determine if they are significantly different. Coupled with the recommended sensitivity analyses, it should be possible to determine whether the difference is expected to affect subjective perceptions of comfort. Not only would this contribute to advancing the theoretical and methodological basis for automobile seat comfort development, it would prevent unnecessary design changes (i.e. those based on effects that do not, in reality, exist).

4. The current state of automobile seat comfort development

Due to the perceived lack of proven analytical metrics, vehicle manufacturers [i.e. original equipment manufacturers (OEMs)] have opted to rely on subjective evaluations as the main indicator of seat comfort. In this context, the OEMs have developed elaborative subjective evaluation protocols (also known as clinics). The protocols usually involve highly structured questionnaires that direct occupants to assign feelings of discomfort to specific regions of the seat. The questionnaires, which typically contain numeric scales (e.g. 1 = very uncomfortable to 9 = very comfortable), produce subjective ratings that are translated into performance requirements/specifications. The nature of the relationship between the OEM and the seat supplier determines who is ultimately responsible for meeting the subjective comfort requirements. There are seat development programs in which the OEMs have completely rid themselves of the seat design responsibility (including comfort performance). This includes the sourcing of subassemblies (e.g. lumbar mechanisms, tracks, recliners, etc.). The seat supplier, in these situations, assumes a leading role. In other programs, the OEMs own the seat design and the seat supplier is simply the manufacturing source. These are obviously the extremes and the seat design responsibility is often divided (not always equally) between the OEM and seat supplier. The relationships are even more complicated as one considers the global perspective. The functional relationship between the same OEM and seat supplier can be different between hemispheres.

To assist the development team (including the supplier) in understanding the performance requirements, target seats are selected through the joint efforts of marketing, engineering, and program management. The decisions are, many times, based on consumer experiences with recently launched products. In this regard, J.D. Power & Associates' (2006) Annual Seat Quality Report is extremely popular. J.D. Power & Associates provide an analysis describing consumer experiences with the quality, design, comfort, and features of their automotive seats. Best-in-class seats are normally targeted.

Although, in some instances (typically due to resource restrictions), a static clinic must suffice. The clinics can be internal (i.e. using employees affiliated with the OEM or seat supplier) or external (i.e. participants are drawn from either the general population or from vehicle owners in a particular market segment). Either way, the feedback, in terms of numeric ratings, is used to steer comfort development for the remainder of the program. That is, prototypes are built and evaluated using the same subjective evaluation approach. More specifically, the target seat is evaluated against the next generation seat until the new program seat meets or exceeds the comfort level offered by the target seat. The purported strength of this process lies in the A to B comparison of seats. A successful program (one that matches the performance of a target seat), since it takes approximately three years to execute, will be just as comfortable as the best seat in the market three years ago. Clearly, this is a problem. It happens even though there is usually some aspect of "futuring" during the target setting process. Futuring is an especially difficult proposition when it comes to seat comfort. In the end, it must be said that excessively long development time impedes advances in comfort (i.e. advances associated with the science of comfort are slow to materialize).

4.1. Limitations of consistent measurement of comfort

Having personally participated in this process on numerous occasions, the author has encountered several noteworthy limitations (in addition to the excessively long development time). For one, there is no research to suggest an appropriate ride & drive duration. At present, the length of the ride & drive is dependent on: (1) cost and (2) how many ratings per seat the development team feels are necessary to yield meaningful results. Assuming an 8-h day, four rotations at 2 h apiece are common. A 2-h rotation allows for ratings to be obtained at different points in the process. There are two underlying assumptions, both of which need to be substantiated: (1) comfort degrades over the course of 2 h rotation and the seat design can somehow combat this and (2) anything over 2 h makes for a long day of travel and can become uncomfortable for reasons other than the seat. With four rotations per day, it is only possible to get four people to evaluate one seat in a day. This is, obviously, too small a number to yield worthwhile results. For this reason, the ride & drive is typically conducted over the course of two days and, even then, at least two samples of each new seat are made available. While adding a significant amount of cost (additional prototype), this yields 16 ratings per seat. The sufficiency of this number, from the perspective of statistical power, is frequently debated.

An additional limitation stems from the fact that the ride & drive process requires a consistent sample of participants/ respondents. Ideally, the participants, because they are representing the consumer, are slanted toward the demographics and anthropometric characteristics of the target buyers. Many times the sample is comprised of key stakeholders in the seat system (i.e. the seat development team). To minimize variations in subjective ratings, each respondent must be committed to the process for the duration of the program. Sample variation, particularly when coupled with questionable statistical power (as previously described), tends to produce a trial-and-error development process in which design modifications made to appease one sample of subjects receive poor ratings from another sample of subjects. Unfortunately, sample consistency is, very often, difficult if not impossible to achieve due to personnel changes (turnover, reassignment, etc.), which are commonplace in the automotive industry.

Program complexity is another factor that complicates the development process. From the seat design team's perspective, the comfort development process requires the evaluation of all seat types (i.e. full bench, split bench, and bucket), content (manual or power adjuster, manual or power recliner, adjustable or fixed head restraint, etc.), features (lumbar, front and/or rear cushion tilt, seat heaters, etc.), trim styles (i.e. base level, mid level, and up level), and fabrics (i.e. cloth, vinyl, leather) available for a particular platform that may include several marketing divisions. Manual transmissions are also a significant subset of certain vehicle lines. The operation of a manual transmission may create unique comfort requirements for the driver. Therefore, where appropriate, each major seat design configuration should be evaluated in a manual and automatic transmission environment. The number of vehicles required for a given ride & drive is based on all of these considerations.

For extremely large programs, it is not uncommon to have 100 different seat configurations. With this type of complexity, it is impossible to evaluate (through a single ride & drive) every possible combination. For this reason, initial comfort evaluations are very often performed on high vehicle volume seats (to the detriment of lower vehicle volume seats). While this appears to be a reasonable compromise it puts the development team at a huge disadvantage. Once an acceptable level of comfort is achieved for the high volume seats, other combinations are evaluated to ensure that comfort is not negatively affected. This usually involves an evaluation of different trim styles. Trim styles typically differ with respect to seam locations. If, for example, a seam in a particular trim style is located in a region that deteriorates seat comfort, efforts are taken to relocate the seam. Unfortunately, by the time the trim style in question is included in a ride & drive, it may be too late to change the design without incurring significant costs.

Another problem with this process is that design direction, early in the program, is based on subjective ratings obtained from seats comprised of skived foam and unrepresentative hardware. Skiving is the process of mechanically shaping a foam pad by cutting it out of block or sheet stock. Skived foam due to differences in material properties and therefore occupant penetration does not feel like molded foam. It should, therefore, not be used to direct decisions regarding cushion length, cushion width, lumbar location, etc. Consider, for example, a scenario in which the lumbar contour was perceived as being too low. With a skived sample, the effect may stem from an excessively firm cushion that did not allow for sufficient penetration. Hardware refers to the handles, switches, and controls used to operate the seat. Unless the production level hardware is used, it is unfair to evaluate functionality (locations, efforts, etc.) with respect to the seat system. Once again, design decisions, based on ride & drive feedback, should be withheld. Molded foam and representative hardware are, unfortunately, not available early in the process.

The process is also rendered ineffective by the fact that the seat interacts with the vehicle system, particularly the interior environment. Vehicles, just like seats, undergo product development cycles. As a result, the power-train, vehicle suspension, and package characteristics (pedal locations, steering wheel position, etc.) are, very often, not finalized until production. This, obviously, affects the seat comfort ratings and associated design decisions.

In summary, the current process is an inefficient and outdated way to develop a comfortable automobile seat. The nature of the ride & drive makes it necessary to investigate the opinions of relatively large groups of occupants in order to determine the impact of various design attributes on impressions of seating comfort (Manenica and Corlett, 1973). This is extremely time consuming [if the key stakeholders in the seat system are spending all this time riding (or developing prototypes for the ride & drive), they are, obviously, not developing the product], expensive (excessive changes lead to tooling iterations), and prone to measurement error. It should also be noted that recent advances in seat comfort evaluation technologies are not reflected in this process.

These limitations could, in some ways, be justified if the process could guarantee a comfortable seat. This is, unfortunately, not the case. Since good seats are an exception and not the rule, it must be concluded that the seat comfort development process is, at least, somewhat ubiquitous and in need of overhaul.

5. Systematic approach to requisite research

Automobile seat comfort research appears to be fragmented. To counter this, the subject matter outlined in Fig. 1 must be systematically and sequentially addressed under the auspices of a unifying theoretical and methodological framework. While there exists a significant amount of published research associated with the defined subject matter, the applications are not immediately apparent to design teams. Instead, they view the published research as a series of independent investigations, unrelated to their existing seat comfort development process. For this reason, they have opted to rely on a process filled with limitations (refer to the preceding section). Automobile seat comfort research would be much more powerful (i.e. it would have a much larger impact) if it fit into a bigger picture. To be applied it must support/satisfy the needs of seat design teams. The remainder of this section describes some of the challenges associated with integrating the requisite research into the design process.

5.1. Define automobile seat comfort

Many within the automotive industry believe that the subjective nature of comfort makes theorizing impossible. This paper's premise is that, at the fundamental level, this difficulty has more to do with the lack of consensus concerning an operational definition of automobile seat comfort. The complications concerning the current development process can also, at least partly, be attributed to the lack of consensus.

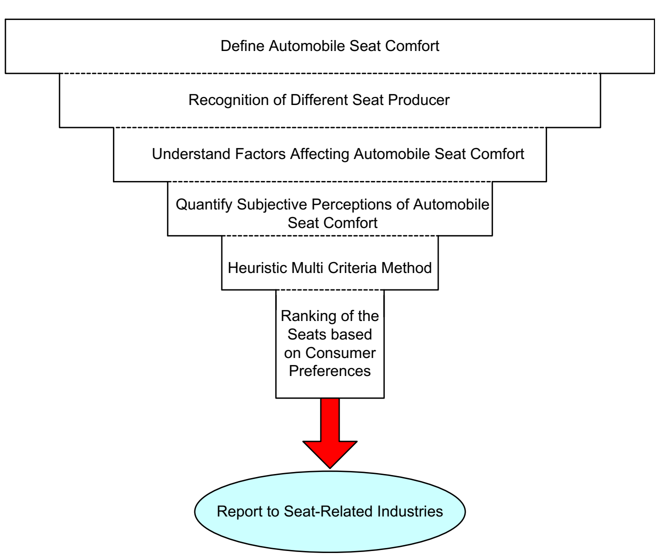

Fig. 1. Research required establishing a theoretical and methodological framework for the science of automobile seat comfort.

Although there exists substantial research in the field of automobile seat comfort, these investigations have generally occurred in a microcosm. Since published definitions reflect the disciplines of the researchers who formulated them, there is no universally accepted operational definition of comfort (Lueder, 1983). An operational definition would allow researchers to establish formal positions that could be advanced and subsequently defended through argumentation (i.e. to formulate testable hypotheses). The preceding sentence basically defines the term thesis. Theses are essential to theory because they integrate groups of fundamental principles underlying a science.

The task of creating a universally accepted operational definition is complex. Consider, for example, the fact that there is little agreement as to whether comfort and discomfort should be regarded as being a bipolar continuum or as composing two experiential dimensions. Branton (1969) assumed that an automobile seat is unlikely to impart a positive feeling to the sitter. That is, the best a seat can do is to cause no discomfort. From the same perspective, Hertzberg (1972) defined comfort as 'the absence of discomfort'. Many of today's researchers have adopted this definition because, in the current environment, it is more straightforward to quantify discomfort than to measure comfort.

Other researchers argue that seat comfort is a bipolar dimension that can be attributed to characteristics of design (Richards, 1980). Evidence to support this claim comes from the fact that occupants, when given the opportunity, rate their subjective responses across an entire continuum, ranging from positive comfort to discomfort.

According to Lueder (1983), comfort relative to automobile seating might be viewed as a function of the patterns of physical supports and constraints on the occupant engaged in the task of driving. As such, comfort may be represented physiologically, psychologically, behaviorally, and in performance. Shen and Vertiz (1997) have proposed that comfort and discomfort coexist as separate dimensions, with the possibilities for comfort increasing when discomfort decreases. They describe comfort as the result of a continuous behavioral process of decreasing discomfort. For example, a wider, more supportive seat may provide better comfort than a narrower seat, even though the narrower seat does not produce a different level of discomfort.

The debate and surrounding controversy concerning an operational definition must be resolved. Until researchers can agree, the discipline will remain splintered by competing schools of thought and several different frameworks. In the end, design teams will continue to produce automobile seats with sub-optimized levels of comfort. While the objective of this paper does not include a position concerning an operational definition of automobile seat comfort, it is, at the time, appropriate to submit a preliminary proposal. Specifically, automobile seat comfort can be defined as a consensually held construct (i.e. a large group of representative subjects perceive the seat in a similar manner) possessing a static and dynamic component that can be manifested objectively (i.e. is consistently quantifiable).

Meantime the seat producer offer their products to the market and consumer would recognize their performance based on their own preferences.

5.2. Understand factors affecting automobile seat comfort

There are many factors that affect automobile seat comfort. User subjectivity, occupant anthropometry, seat geometry, and amount of time spent sitting have previously been cited (Thakurta et al., 1995). The growth of the international automotive market, which has served to increase diversity in seat design, is another factor. In other words, unique, but functionally equivalent, seats are required to satisfy culture-based preferences and expectations of seat comfort. Western Europeans, for example, are generally, thought to prefer firmer seats as compared to North Americans. Fig. 2 builds on the preceding factors to provide a more complete, although definitely not comprehensive, list. It demonstrates the multi-faceted nature of automobile seat comfort. The following explanations offers a little more insight into the rationale used for including the factors outlined in Fig. 2.

Vehicle package, which may represent a segment-specific effect (i.e. seats in the same market segment probably have comparable packages), is thought to be a primary determinant of seat comfort. Vehicle package defines roominess (i.e. headroom, legroom, shoulder room, and hip room). It is reasonable to contend that the same seat, when placed in two different packages, will receive different comfort ratings. Similarly, the same seat, when sold under a different nameplate, may receive different comfort ratings.

Nameplate is related to purchase price of vehicle. For the purposes of this discussion, both nameplate and purchase price of vehicle are considered social factors. Individual factors, like age and body size, are thought to affect subjective perceptions of comfort. Posture may be the most important individual factor. While the effect of posture is assumed to be significant, it is difficult to address because occupants with similar anthropometric characteristics may sit in completely different body positions. The study of seated posture is an active and worthwhile area of future research. Stiffness, geometry, contour, breath ability, and styling are considered seat factors. Stiffness refers to the resiliency of the seat system. Geometry defines seat shape in terms of width, length, and height, whereas contour deals with the profile of the seated surface (e.g. location and prominence of lumbar apex). The seat's geometry and contour must accommodate the anthropometric variability of the target population. Breath ability, as it pertains to the soft trim (i.e. foam density and fabric construction), may affect automobile seat comfort in extreme environmental conditions. Styling must be included as a seat factor because aesthetic quality may affect perceptions of comfort, in the same way as nameplate or purchase price of vehicle.

There are other factors, not shown in Fig. 3, which may indirectly affect subjective perceptions of seat comfort. It is conceivable that a problem with quality, as indicated by durability or noise [i.e. (1) buzz, squeak, and rattle, (2) road, wind, engine, and tire noise, and/or (3) radio and music system acoustics], may negatively affect the consumer's opinion of the entire vehicle, including seat comfort. The same can be said for problems with the HVAC system [temperature, humidity, and air quality (cabin climate)], the instrument panel controls [in terms of reach and touch (i.e. location of features, ease of operation, and visibility and lighting)], and storage.

There are also important interactions between the factors listed in Fig. 3. These interactions can and should be studied. While this is more difficult than it appears, factor analysis may help to reduce the problem to more manageable proportions. Once identified, the critical interactions can be formulated into hypotheses that lend themselves well to the investigative process familiar to most researchers. Consider, for example, the relationship between seat height (listed as a vehicle/package factor) and posture (listed as an individual factor), as manifested through occupant selected seat position. It is known that humans search instinctively for the body posture allowing the lowest expenditure of energy within the limits of that which is physiologically and biomechanically possible, as well as that which allows an ease and efficiency in task execution (Judic et al., 1993). It is impossible to quantify automobile seat comfort without first defining a space in which a postural compromise is possible. The seat adjusters, in combination with the anthropometric characteristics of the occupant, help to define this space.

An understanding of the contributing factors (and interactions), as they relate to a universally accepted operational definition of

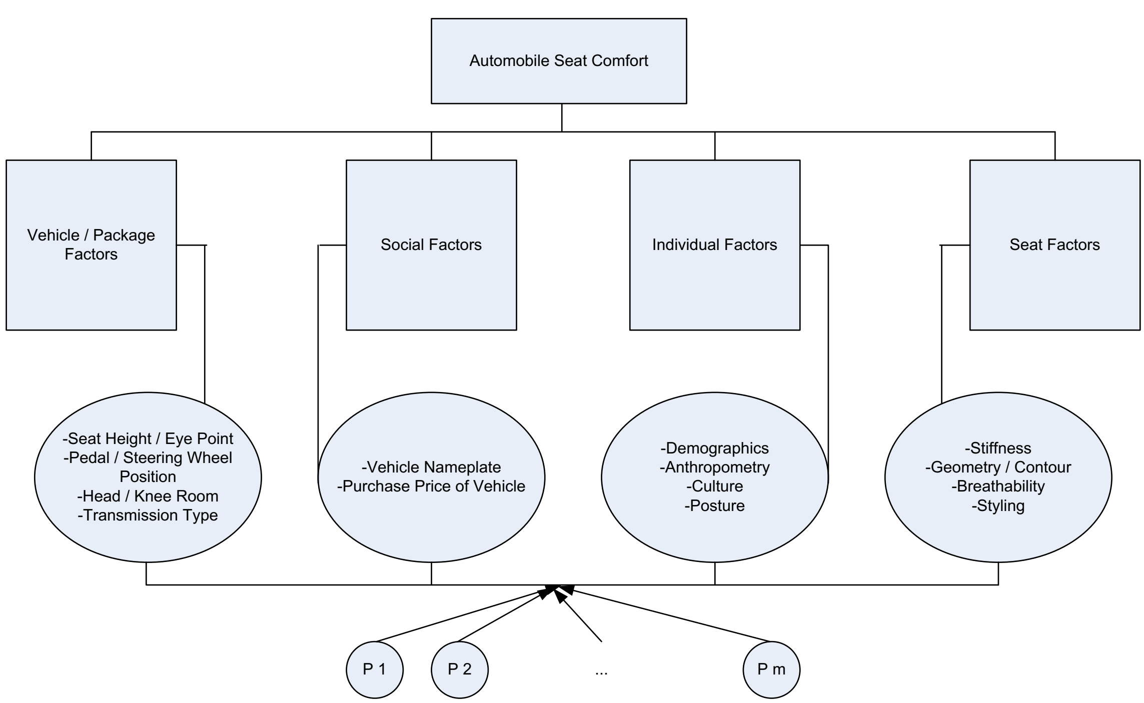

Fig. 2. Factors affecting subjective perceptions of automobile seat comfort.

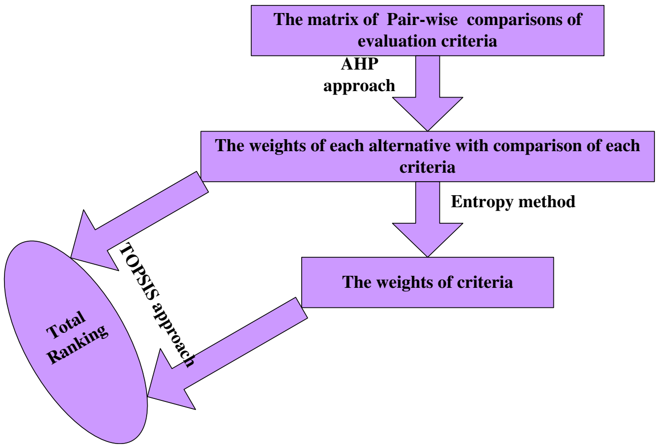

Fig. 3. The methodology of the proposed model.

automobile seat comfort is essential to the development of a theoretical and methodological research basis.

5.3. Quantify subjective perceptions of automobile seat comfort

After operationally defining comfort and understanding the contributing factors, the task becomes one of quantification. This includes the subjective data, which, as previously described, are typically obtained through structured questionnaires included as an integral part of the ride & drive process. In this context, a properly designed questionnaire (i.e. one that is crafted from the perspective of a universally accepted operational definition of automobile seat comfort and one that addresses the critical factors affecting automobile seat comfort) is paramount because it affords researchers an instrument from which to establish theories. The lack of emphasis on seat comfort questionnaire design (exceptions include Reed et al., 1991a,b; Shen and Parsons, 1997; Kolich, 1999; Kolich and White, 2004) is surprising given: (1) the extent to which seat comfort development relies on questionnaire data and (2) the fact that many of the problems related to the collection of subjective data have been well known for some time (particularly in domains like psychology).

A good questionnaire is reliable and valid. This involves reducing the questionnaire measures into two components: a true score component and a measurement error component. A reliable questionnaire item contains little measurement error. It is, however, impossible to directly observe the true score and error components of an actual score on a questionnaire item. Instead, correlation techniques are used to give an estimate of the extent to which the questionnaire item reflects true score rather than measurement error. Important indicators are test–retest reliability, internal consistency, criterion-related validity, construct related validity, and face validity (Kolich, 1999; Kolich and White, 2004).

Reliability and validity can be assured by considering the following principles: (a) the wording of questionnaire items (Oppenheim, 1966), (b) the number of rating scale categories (Guilford, 1954; Grigg, 1978), (c) the verbal tags associated with the categories (Osgood et al., 1957), and (d) the interest and motivation of the respondent, as a function of questionnaire length. The type of rating scale (i.e. nominal, ordinal, interval, or ratio) must also be considered, since seat comfort questionnaires are, typically, subjected to some form of quantitative analysis, whether it is a simple frequency count or a more complex statistical treatment (Stevens, 1946; Cozby, 1989). Only when the method of quantification is well thought-out, can the questionnaire results be used as the basis for design decisions. Failure to attend to the quantitative aspects of questionnaire design will produce results that are, at best, biased and, at worst, totally invalid. This obviously has a detrimental effect on the advancement of theory and it forces comfort development to take on a trial-and-error approach. As previously indicated, this is an expensive and inefficient way to impact design.

At a minimum level, if researchers were to apply a questionnaire developed with this type of rigor, along with a structured data analysis approach, the current process would improve. This paper aims higher. Specifically, a good questionnaire could be used to define meaningful dependent variables for the purposes of prediction. This notion, in terms of its impact on the creation of a theoretical and methodological basis for the science of automobile seat comfort, is described later in this section.

As an interesting alternative to questionnaires, Desmet et al. (2000) has developed a method using emo-cards. This system uses 16 cards that show faces with varying emotions. A test subject is asked to choose the card that best fits with their emotion on seeing the product or a precursor of the product in drawing form. Firstly, they use the cards to define the ideal emotion related to the product (in this case, the automobile seat). Then several seats are rated and the best can be chosen. Novel approaches to quantifying subjective perceptions of automobile seat comfort have a definite place in the proposed framework. Next section describes the heuristic method which is applied to quantify seat comfort of any seat producer based on consumer preferences.

5.4. Multi-criteria decision making

Multi-criteria decision making (MCDM), which deals mainly with problems about evaluation or selection (Keeney and Raiffa, 1976; Teng, 2002), is a rapidly developing area in operational research and management science. The complete MCDM process involves the following basic elements: criterion set, preference structure, alternative set, and performance values (Yu, 1985). While the final decision will be made based on the performance of alternatives, a well-defined criterion set and preference structure are key influential factors and should be prepared in advance. In order to obtain the criterion set and preference structure, a hierarchical analysis must be carried out. Such an analysis helps decision makers to preliminarily derive an objective hierarchy structure to demonstrate the relationship between the goal and the decision criteria (MacCrimmon, 1969). The goal of the hierarchy may be “a perceived better direction of a decision organization” (Teng, 2002). On the other hand, the criteria represent the “standards for judging” (Hwang and Masud, 1979), which should be complete, operational, decomposable, non-redundant, and minimal in size (Keeney and Raiffa, 1976; Teng, 2002). Based on this hierarchy structure, decision makers can set about deriving the relative importance of the criteria and then assessing alternatives against each criterion. By integrating the assessments of alternatives with the relative importance of criteria, an organization can select one alternative which best meets its requirements to accomplish its goal.

The Analytical Hierarchy Procedure (AHP) method (Saaty, 1977, 1980) is used to face complex decision-making problems. Fundamentally, AHP works by developing priorities for goals in order to value different alternatives. This multi-criteria method has become very popular among operational researchers and decision scientists (Dyer and Forman, 1992; Eom and Min, 1999; ADoumpos and Zopundnidis, 2002).

Basically, AHP fits our purposes better because it has methodological tools for (1) structuring the decision problem, (2) weighting criterions/goals and alternatives and (3) analyzing judgment consistency. As negative points, it requires a larger number of inputs than other discrete multi-criteria methods. Nevertheless, these inputs can be reduced by optimizing the hierarchy.

As we have mentioned before, the AHP method has tools for consistency analysis. The most-used tool is the Consistency Ratio (CR). The CR tests the consistency of each decision matrix A. A totally consistent matrix A has a CR equal to 0. Notwithstanding, a CR ratio less than 0.1 is acceptable (Saaty, 1980) for solving expression. In case of group decision making, the most extended tool for aggregating the expert judgments is the geometric mean over the numeric entries of the paired comparisons a_{ij} (Saaty and Vargas, 2001). Sometimes there are a large number of alternatives that need to be assessed. In these cases, the absolute measurement can be applied to rank the alternatives.

In this study first we apply AHP method which is one of the main techniques for the multi-attributes decision making (MADM) problem. It can be used to evaluate an alternative from the set of alternatives, characterized in terms of their attributes. It is based on a simple intuitive concept, but it enables systematic and consistent aggregation of attributes.

Entropy is a main technique in physics, sociology and information theory which indicates the uncertainty in the expected content of the information. In another word entropy is a criterion to express the amount of the uncertainty based on a discrete probability distribution (P_i). A short description of that uncertainty is as follows:

Initially the E value is defined as follows:

$$E \approx S\{p_1, p_2, \ldots, p_n\} = -K\sum_{i=1}^{n}[p_i \ln p_i], \tag{1}$$

where K is a positive constant value to guarantee $0 \le E \le 1$. E is calculated regarding to a statistical mechanism from P_i probability distribution and when the P_is are equal, i.e.$p_i = \frac{1}{n}$, then E gets its maximum value, as follows:

$$\begin{aligned} -k\sum_{i=1}^{n} p_i \ln p_i &= -k\left\{\frac{1}{n}\ln\frac{1}{n} + \frac{1}{n}\ln\frac{1}{n} + \cdots + \frac{1}{n}\ln\frac{1}{n}\right\} \\ &= -k\left\{\left(\ln\frac{1}{n}\right)\left(\frac{n}{n}\right)\right\} = -k\ln\frac{1}{n}. \end{aligned} \tag{2}$$

Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), known as a classical MCDM method, has been developed by Hwang and Yoon for solving the MCDM problems. The basic principle of the TOPSIS is that the chosen alternative should have the “shortest distance” from the positive ideal solution and the “farthest distance” from the negative ideal solution. The TOPSIS introduces two “reference” points, but it does not consider the relative importance of the distances from these points.

Based on the hierarchy structure, deriving the preference structure, explores learners’ perceptions of the relative importance of the criteria and the sub-criteria of these criteria. This may help answer what it is that users regard highly in terms of learner satisfaction in the context of WELS. In this paper a heuristic method is applied which is a combination of AHP (Analytical Hierarchy Procedure), Entropy, and TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) that we call it AET method. The methodology of the proposed model is presented in Fig. 3.

5.4.1. AET algorithm

The AET algorithm is summarized as the following steps.

Step 1. Define the decision problem and goal.

Step 2. Structure the hierarchy from the top through the intermediate to the lowest level which usually contains a list of alternatives.

Step 3. Construct the Producer–criteria matrix by steps 3-1 to 3-5 by AHP method.

Step 3-1. Matrices of pair-wise comparisons are constructed for each of the lower levels with one matrix for each element in the level immediately above by using a relative scale measurement. The decision maker has the option of expressing his or her intensity of preference on a nine-point scale. If two criteria are of equal importance, a value of 1 is given in the comparison, while a 9 indicates an absolute importance of one criterion over the other. Table 1 shows the measurement scale defined by Saaty (1977, 1980).

Step 3-2. Computation of eigenvalue by the relative weights the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.

Pair wise comparison data can be analyzed using the eigenvalue technique. Using these pair wise comparisons, the parameters can be estimated. The right eigenvector of the largest eigenvalue of matrix A constitutes the estimation of relative importance of attributes.

Step 3-3. Consistency and consequence weights analysis.

$$A = (a_{ij}) = \begin{bmatrix} 1 & w_1/w_2 & \ldots & w_1/w_n \\ w_2/w_1 & 1 & \ldots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \ldots & 1 \end{bmatrix}, \tag{3}$$

If matrix A is consistent (that is,$a_{ij} = a_{ik}a_{kj}$ for all $i, j, k = 1, 2, \ldots, n$), then A contains no errors (the weights are already known) and we have

$$a_{ij} = w_i/w_j, \quad i,j = 1, 2, \ldots, n. \tag{4}$$

If the pair wise comparisons do not include any inconsistencies, $\lambda_{\max} = n$. The more consistent the maximum comparisons are, the closer the value of computed $\lambda_{\max}$ to n. A consistency index (CI), which measures the inconsistencies of pair-wise comparisons.

$$\mathrm{CI} = \frac{(\lambda_{\max} - n)}{(n-1)}. \tag{5}$$

A consistency ratio (CR) is given as,

$$\mathrm{CR} = 100\left(\frac{\mathrm{CI}}{\mathrm{RI}}\right), \tag{6}$$

where CI is the consistency index; RI is the random index; and n is the number of columns. The RI is the average of the CI of a large number of randomly generated matrices, where n is the matrix size.

RI depends on the order of the matrix. CR of 10% or less is considered acceptable (Saaty, 1980).

Steps 3-1 to 3-3 are performed for all levels in the hierarchy. Fortunately, there is no need to implement the steps manually.

Table 1
The criteria preferences with their numerical values.

Preferences	Numerical value
Extremely Preferred	9
Very Strongly Preferred	7
Strongly Preferred	5
Moderately Preferred	3
Equally Preferred	1
Preferences among the above preferences	2,4,6,8

Table 2
The Producer–sub criteria matrix.

	SC_1	SC_2	…	SC_{13}
Producer 1	$W'_{1,1}$	$W'_{1,2}$	…	$W'_{1,13}$
Producer 2	$W'_{2,1}$	W'_{22}	…	$W'_{2,13}$
			…	
Producer m	$W'_{m,1}$	$W'_{m,2}$	…	$W'_{m,13}$

Step 3-4. The producer–sub criteria and the sub criteria–criteria matrix is configured as follows (Tables 2 and 3):

Step 3-5. The Producer–criteria matrix is formed as follows:where

$$R_{pq} = \sum_j W'_{pj} \times W_{jq} \quad \forall p = 1, \ldots, m, \;\; q = 1, \ldots, 4$$

and j is the number of sub criteria with respect to ith criterion.

Step 4. Calculating the weights of criteria by using Entropy method.

Step 4-1. A normalized decision matrix which has been gained by AHP method and shown in Table 4 For the set of R_{ij} we can calculate E_j:

$$E_q = -k \sum_{p=1}^{m} \left[R_{pq} \ln R_{pq} \right], \quad 1 \le q \le 4, \tag{7}$$

So that,

$$k = \frac{1}{\ln m}, \tag{8}$$

Step 4-2. The uncertainty in decision making or deviation degree (d_q) for qth criteria is as follows:

$$d_q = 1 - E_q; \quad 1 \le q \le 4. \tag{9}$$

Step 4-3. The weights (w_q) for the criteria are calculated as follows:

$$w_q = \frac{d_q}{\sum_{q=1}^{4} d_q}, \tag{10}$$

Step 5. Obtaining the weight of Producers by TOPSIS.

Step 5-1. Determine the positive ideal solution (*PIS*) and negative ideal solution (*NIS*) by:

$$PIS = \left\{ \underset{p}{\mathrm{Max}}\, R_{pq}; q \in J \right\} \cup \left\{ \underset{p}{\mathrm{Min}}\, R_{pq}; q \in J' \right\} = \left\{ r_1^*, r_2^*, r_3^*, r_4^* \right\}, \tag{11}$$

$$\mathrm{NIS} = \left\{ \underset{p}{\mathrm{Min}}\, r_{pq}; q \in J \right\} \cup \left\{ \underset{p}{\mathrm{Max}}\, r_{pq}; q \in J' \right\} = \left\{ r_1^-, r_2^-, r_3^-, r_4^- \right\}, \tag{12}$$

Table 3
The sub criteria–criteria matrix.

	C1	C2	C3	C4
SC_1	$W_{1,1}$	$W_{1,2}$	$W_{1,3}$	$W_{1,4}$
SC_2	$W_{2,1}$	W_{22}	$W_{2,3}$	$W_{2,4}$
…				
SC_{14}	$W_{14,1}$	$W_{13,2}$	$W_{14,3}$,	$W_{14,4}$

Table 4
The Producer–criteria matrix.

	C_1	C_2	C_3	C_4
Producer 1	R_{11}	R_{12}	R_{13}	R_{14}
Producer 2	R_{21}	R_{22}	R_{23}	R_{24}
⋮	⋮	⋮	⋮	⋮
Producer m	R_{m1}	R_{m2}	R_{m3}	R_{m4}

where J is associated with benefit criteria, and J' is associated with the cost criteria.

Step 5-2. Calculate the separation measures, using the n-dimensional Euclidean distance. The separation of each Producer from the positive ideal solution is given by:

$$d_p^+ = \left\{ \sum_{q=1}^{m} \left(r_{pq} - r_q^* \right)^2 \right\}^{\frac{1}{2}}, \quad 1 \le p \le 4. \tag{13}$$

Similarly, the separation from the negative ideal solution is given by:

$$d_p^- = \left\{ \sum_{q=1}^{m} \left(r_{pq} - r_q^- \right)^2 \right\}^{\frac{1}{2}}, \quad 1 \le p \le 4. \tag{14}$$

Step 5-3. Calculate the relative closeness to the ideal solution. The relative closeness of alternative A_i with respect to PIS is defined by:

$$CC_{p*} = \frac{d_p^-}{d_p^- + d_p^+}, \quad 1 \le p \le 4. \tag{15}$$

Since $d_p^- \ge 0$ and $d_p^+ \ge 0$, then clearly, $CC_{p*} \in [0, 1]$.

Step 6. Rank the preference order. For ranking alternatives using this index, we can rank alternatives in decreasing order.

5.5. *Advantages of the proposed approach*

The advantages of the proposed approach are hierarchical structure of the model which considers various parameters and their corresponding weights in the decision making process. On the other hand, by applying the entropy technique in the AET method, some uncertainty in the decision making is considered which makes the AET method more useful due to the stochastic nature of the decision making on the anthropometric parameters of seat comforts. Also, using the concept of closeness in TOPSIS algorithm provides an opportunity to investigate the ranges in anthropometric and biomechanics criteria. Moreover, the AET method is much more easily used, because we use some mathematical equations to analyze the collected data from the customers. As

Table 5
Criteria with sub-criteria.

		Sub criteria	Criteria
1	Seat height	21.4	21.4
2	Vehicle nameplate	22	20.8
		21.4	
		19	
3	Demographics	18.8	20.3
		20.6	
		21.4	
4	Stiffness	23.2	21.9
		20.6	

Table 6
Pair wise comparison matrix.

Criteria	1	2	3	4
1	1	1.03	1.05	0.98
2	0.97	1	1.02	0.95
3	0.95	0.97	1	0.93
4	1.02	1.05	1.08	1

Table 7
Normalized pair wise comparison matrix.

	1	2	3	4
1	0.17762	0.177893	0.177066	0.177858
2	0.172291	0.172712	0.172007	0.172414
3	0.168739	0.16753	0.168634	0.168784
4	0.181172	0.181347	0.182125	0.181488

Table 8
Weight of each alternative in relation with each criterion.

	Alternative1	Alternative2	Alternative3
Criteria1	0.525207	0.334032	0.140761
Criteria2	0.297424	0.539292	0.163284
Criteria3	0.557343	0.320338	0.122319
Criteria4	0.25145	0.589692	0.158858

Table 9
The p_{ij} Matrix.

	Criteria 1	Criteria 2	Criteria 3	Criteria 4
Alternative1	0.525207	0.297424	0.557343	0.25145
Alternative2	0.334032	0.539292	0.320338	0.589692
Alternative3	0.140761	0.163284	0.122319	0.158858

Table 10
The $p_{ij}*lnp_{ij}$ Matrix.

	Criteria 1	Criteria 2	Criteria 3	Criteria 4
Alternative1	−0.338213775	−0.360655316	−0.325808466	−0.34712952
Alternative2	−0.366272262	−0.333011791	−0.364665921	−0.311448727
Alternative3	−0.275988947	−0.295913758	−0.257007251	−0.292258141
SUM	−0.980474984	−0.989580865	−0.947481638	−0.950836388

Table 11
The E_j for all alternatives.

E_1	E_2	E_3	E_4
0.892466791	0.900755321	0.862434954	0.865488578

Table 12
The uncertainty in decision making or deviation degree.

D_1	D_2	D_3	D_4
0.107533209	0.099244679	0.137565046	0.134511422

Table 13
The weights for the criteria.

W_1	W_2	W_3	W_4
0.136323716	0.125816048	0.174396156	0.170524967

Table 14
The weight of alternatives by TOPSIS.

	Criteria 1	Criteria 2	Criteria 2	Criteria 4
Alternative1	0.07159817	0.037420712	0.097198477	0.042878503
Alternative2	0.045536484	0.067851588	0.055865716	0.100557209
Alternative3	0.019189063	0.020543748	0.021331963	0.027089255

Table 15
The separation measures.

Criteria 1	Criteria 2	Criteria 3	Criteria 4
a^+ Matrix			
0.019189063	0.067851588	0.097198477	0.100557209
a^- Matrix			
0.07159817	0.020543748	0.021331963	0.027089255

Table 16
The relative closeness to the ideal solution.

d_1^+	d_2^+	d_3^+
0.093316574	0.097325704	0.174472142
d_1^-	d_2^-	d_3^-
0.13702533	0.125520745	0.052409107
$d_1^+ + d_1^-$	$d_2^+ + d_2^-$	$d_3^+ + d_3^-$
0.230341903	0.222846449	0.22688125
Closeness_1^+	Closeness_2^+	Closeness_3^+
0.594877994	0.563261139	0.230997967

Table 17
The Rank of the preference order.

Ranking	Alternative
1	Alternative 1
2	Alternative 2
3	Alternative 3

a result, customers' preferences are directly included in the seat comfort development. Further, in previous methods only two alternatives (seats) could be compared, i.e., one by one comparison, but in our proposed approach it is possible to compare many

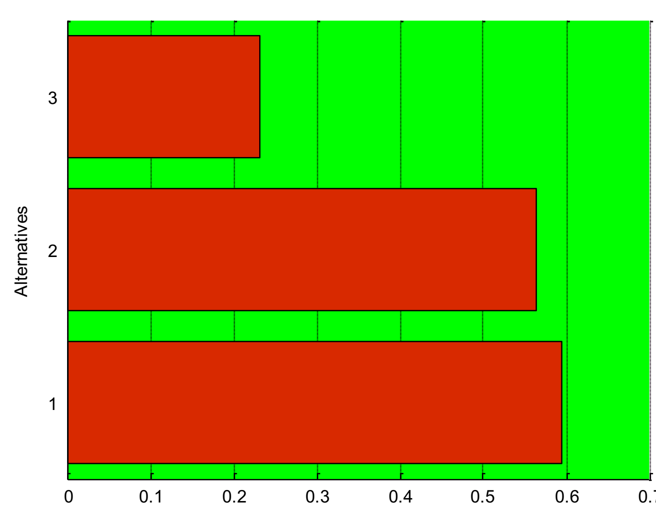

Fig. 4. The alternatives and their corresponding values.

alternatives with each other at the same time and comprehensive ranking of alternatives is obtained. In the previous qualitative methods various analyses should be performed to gain a reliable result about seat comfort, but the proposed AET provides a mathematical algorithm with low complexity for decision making on seat comfort. Another advantage of AET is in including the whole customers' preferences in decision making despite sampling in previous approaches which violated the concept of comfort due to lack of input information. Easily, with a web-based customer relationship management system a seat company can collect all its customers' preferences. As mentioned in Section 5.2, different parameters are considered in the process of comparing seats from comfort viewpoint which makes the proposed algorithm flexible in confronting various situations and geographical area.

6. Case study

To survey the applicability and effectiveness of the proposed heuristic approach, we conducted a case study in the province of Mazandaran in north part of Iran. In this case, we chose three seat products ans investigate them from comfort viepoints. Due to secrecy we wont state the brand of the seat products and just call them alternatives from so on. The AET (AHP-Entropy-TOPSIS) method is a hybridization of AHP, Entropy and TOPSIS methods, for which we use the abbreviation AET. We start from a questionnaire which covers all the criteria and sub criteria. The questionnaire should be prepared in a way that each individual can state the importance of the criteria and sub criteria to him/her. For showing the criteria (sub criteria) numerical values 1 up to 5 have been used (1. for not important at all, 2.for not very important, 3. for important, 4. for very important, and 5. for essential).

After collecting the questionnaires from some of the automobile consumers in Mazandaran, we would find out the degree of importance the respondent attached to each sub criterion. The value of each criterion is calculated by multiplying the number of people that have selected the sub criteria for each criterion and by making a geometric average for them. The results of these calculations are shown in Table 5.

Here, we calculate the final weights of the options using the AHP method. In order to complete the matrix of the two by two comparisons, we referred to expert of seat industry. The two by two comparison matrix and normalized matrix are shown in Tables 6 and 7, respectively. The weight of each alternative in relation with each criterion is shown in Table 8.

Then we calculate the weights of criteria using the Entropy method. First, we calculate the normalized decision matrix, which has been gained by AHP method as shown in Table 7. For the set of r_{ij} , first we calculate the p_{ij} as presented in Table 9, then the $p_{ij}{}^{*}\ln p_{ij}$ is computed as indicated in Table 10, and finally the E_j is calculated, as shown in Table 11.

k is a positive constant value to guarantee $0 \leq E \leq 1$. $k = 0.910239227$.

The uncertainty in decision making or deviation degree (d_q) for criterion q is as follows (Table 12):

The weights (w_q) for the criteria are calculated as follows (Table 13):

Now, we obtain the weights of the alternatives by TOPSIS. The following table (Table 14) is gained using Tables 8 and 13.

After that, we determine the positive ideal solution (PIS) and the negative ideal solution (NIS). We calculate the separation measures, using the n-dimensional Euclidean distance. The separation of each alternative from the positive ideal solution is given by Table 15.

Here, we calculate the relative closeness to the ideal solution. The relative closeness of alternative A_i with respect to PIS is defined by Table 16.

As a result, we rank the preference order. For ranking alternatives using this index, we can rank alternatives in decreasing order (Table 17).

It is interesting to state that in the current market of Mazandaran automobile company alternative 2 is assumed to provide more comfort, but it is presented that an algorithmic approach (AET method) using real concepts and information derived from customers achieves different option (alternative 1). The ranking associated with the corresponding values is represented in Fig. 4.

This way, we verified our proposed approach in a real case study. The ranked one alternative is the optimal option for the customers considering comfort viewpoint.

7. Conclusion

The proposed conceptual framework of this paper, which was derived from the drawbacks associated with consumer's preferences, is offered as an enabling mechanism. The contribution of this work is proposing a novel approach to investigate seat comforts in automobile industry. It demonstrated a heuristic method to quantify seat comfort parameters based on consumer's preferences about the concept of comfort among as many seats that produce for varied automobiles. As a result the best seat would be identified and it would help the seat industries to find out the strengths and weaknesses of their own products which lead them to enhance or improve their seat design. The applicability and effectiveness of the proposed approach was verified and reported in a case study in Mazandaran province, north part of Iran.

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