Adjustments in production costs linked to the redesign of wooden chairs for the bariatric population

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Abstract

Purpose – Current furniture design principles fail to keep pace with the global rise in obesity. This study aims to address this issue by proposing a novel methodology for manufacturing cost estimation of common-use chairs that can accommodate even severely obese individuals.

Design/methodology/approach – The approach prioritizes universal design principles and user safety while ensuring furniture producers' economic viability. This study utilizes real-world data to determine the establish appropriate load capacity for common-use chairs. Empirical height and weight data were collected from 7,938 young Slovakian men (aged 18–25) between 2001 and 2023. Additionally, data on Slovakia's bariatric population, encompassing all genders, were obtained from medical facilities (2020–2024).

Findings – Considering the 95th percentile weight among bariatric individuals, the authors factored in a 20% design safety margin. This resulted in a target load capacity of 230 kg for all chairs designed for common use – a significant increase from the standard 110 kg capacity. An essential contribution of this study is a method for estimating chair production cost based on its designed load capacity. This method's calculations reveal that the redesigned chair is estimated to cost 11.6% more than a standard chair. However, considering its ability to cater to broader user needs, this price point remains competitive.

Practical implications – The research indicates that the standard load capacity of common-use chairs should be substantially increased to accommodate the growing obese population. The study offers a methodology for estimating the cost implications of designing chairs with a higher load capacity, enabling manufacturers to assess the economic feasibility of implementing such changes.

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Ethics statement: This research did not involve human subjects or the collection of any sensitive personal data. All data used in this study was derived from existing literature. The analysis described was conducted under ethical principles and guidelines, adhering to the standards outlined in the Declaration of Helsinki.

Data availability statement: The authors confirm that the data supporting the findings of this study are available within the article.

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Social implications – Chairs with higher load capacities improve accessibility for individuals with obesity, promoting their participation in social and professional activities. By accommodating individuals of all sizes, these chairs reduce the risk of falls, injuries and other problems associated with poorly fitting furniture.

Originality/value – This study links universal design, safety and affordability. The authors used real data from Slovakia to find the right weight limit for these chairs. The study addresses the pressing issue of furniture design failing to keep pace with rising obesity rates. The method helps make chairs that are accessible to everyone. While these chairs cost a bit more, they are affordable considering their expanded user base. The study's originality lies in its novel methodology and data-driven approach, while its value lies in its potential to address a significant societal issue.

Keywords Anthropometry, Inclusive design, Load capacity for chairs, Manufacturing cost estimation, Furniture safety, Furniture design

Paper type Research paper

1. Introduction

Secular trends are long-term changes observed in various phenomena, including human stature and weight growth. Global trends indicate a significant increase in adult height over the past 150 years but with regional variations (Fudvoye and Parent, 2017). Historical data from the 19th century onwards consistently demonstrates this phenomenon, particularly in European countries, where adult height has been observed to increase by up to 30 mm per decade (Cole, 2000).

Body mass index (BMI) is a measurement that uses body height and weight to measure the quantity of obesity (Keys *et al.*, 1972). The World Health Organization defines adult obesity as a BMI of 30 or more. Class 1 obesity means a BMI of 30–34, Class 2 obesity is a BMI of 35–40 and Class 3 obesity is a BMI of 41 or more, also known as severe obesity (Obesity: Preventing and Managing the Global Epidemic. Report of a WHO Consultation, 2000).

Although stature growth is beginning to slow, body mass growth is accelerating in many countries (Popkin and Gordon-Larsen, 2004; Parra *et al.*, 2024). The worldwide prevalence of obesity has doubled since 1980, with nearly a third of the world's population now classified as overweight or obese. Obesity rates have increased in all ages and both sexes, regardless of geographical locality, ethnicity or socioeconomic status (Chooi *et al.*, 2019). Current prevention and treatment strategies for obesity have limited effectiveness (Blüher, 2019), and obesity is more common than underweight (Lin and Li, 2021).

As human bodies become taller and heavier, regulations for designing everyday items like furniture and clothing should be reviewed (Wongwien and Nanthavanij, 2017; Koman *et al.*, 2022). Seating furniture presents novel design challenges related to increased user weight capacity (Hitka *et al.*, 2023) and the ability to accommodate a broader range of user sizes (Hitka *et al.*, 2022b; Sydor and Hitka, 2023).

A comprehensive report on the European bariatric population market underscores emerging trends and demands for specialized furnishings, including chairs and beds specifically designed for this population (Bora, 2024). While not conducted as a survey, the report offers valuable insights into the market's needs and preferences regarding furniture crafted for larger individuals. The results reflect a growing recognition of the significance of appropriate furniture solutions to enhance comfort and safety for all. The increasing incidence of excess adiposity underscores the necessity of acknowledging that design requirements applicable to all must also incorporate the specific needs of the bariatric population (Ortiz *et al.*, 2021). The emphasis on durability and stability indicates that chairs must support higher weight capacities without compromising safety.

Beyond safety, comfort is paramount, requiring wider seating and ample padding to accommodate larger body types. Furthermore, universal design is crucial, emphasizing the need for ergonomic features that facilitate both sitting and rising from the chair. Finally, aesthetic appeal is vital, advocating for designs seamlessly integrating functionality with style across diverse environments, including residential and commercial spaces.

If newly manufactured furnishings are not tailored to accommodate individuals with obesity, there may be significant repercussions. Chairs with insufficient weight capacity risk breakage under heavier users, potentially leading to falls and injuries. Additionally, furniture not designed for a broader range of body sizes can contribute to improper posture, back pain and other musculoskeletal issues in obese individuals. Mismatched or uncomfortable furniture in public spaces could also lead to social exclusion and feelings of isolation. From a market perspective, failing to adapt furniture to diverse body types can lead to missed opportunities. Furniture manufacturers who do not cater to the growing obese population might miss out on a significant market segment, and a lack of inclusivity could lead to negative brand perception. Furthermore, public spaces and workplaces with noninclusive furniture could create accessibility barriers for a significant portion of the population.

Current standards, such as EN 1729:2015 (EN 1729, 2015) (which outlines the functional dimensions of chairs in educational institutions), specify a seat width of only 40 cm for the tallest students (up to 207 cm). A broader seat width range is needed to include bariatric users for all common-use chairs. American National Standards Institute (ANSI)/ Business and Institutional Furniture Manufacturers Association (BIFMA) X5.41-2021 for Large Occupant Public and ANSI/BIFMA X5.41-2021 (2021) recommends minimum widths of 55.9 cm for the 99th percentile (181 kg/400 lb) and 66.0 cm for 272 kg (600 lb) users. It is worth mentioning that the literature suggests even wider seats for bariatric users: 67 cm for the 95th percentile and 73 cm for the 99th percentile (Hitka *et al.*, 2022b).

According to EN 12520 (EN 12520, 2015) standard, the required load capacity for a general-use chair is only 110 kg, whereas EN 1728 (EN 1728:2012/AC:2013, 2013) requires 130 kg (1300 N) during testing. The ANSI/BIFMA standard, X5.11–2015, "ANSI/BIFMA X5.11-2015 (R2020), 2015, specifies chair load-bearing capacity for individuals weighing up to 181 kg (400 lb), representing the 99.5th percentile male in the US population. The another standard, ANSI/BIFMA X5.41–2021, "Large Occupant Public and ANSI/BIFMA X5.41-2021 (2021)", points out two load-bearing capacity grades: 181 kg (400 lb) and additionally 272 kg (600 lb). As it is known, all technical standards, like the European Standards (EN), the ANSI and the BIFMA, are voluntary consensus (there is no enforcement body for these standards). However, some countries or regions have building codes or regulations referencing these standards. In such cases, following the standard becomes indirectly mandated. Similarly, if a contract for furniture specifies following these standards, it becomes mandatory within that particular agreement.

Our preliminary research focus was guiding our inquiry into the notion that although furniture safety standards are not mandatory, manufacturers ought to be motivated to voluntarily enhance the load-bearing capacity of their chairs while concurrently managing production costs. The subsequent investigation tackles two central research questions:

Q1. What is the ideal design load capacity for conventional chairs?

Q2. To what extent do adjustments in production costs differ for chairs designed for this new capacity compared to those conforming to the EN standards?

Our contribution is structured as follows. Initially, we provide a comprehensive literature review that addresses the population's evolving needs concerning the furniture industry. The methodology section outlines the foundational aspects of our modeling approach and the variables used to establish appropriate measurements pertinent to the Slovak population. Subsequently, we present the primary results of our analyses alongside significant empirical findings. Finally, the discussion section concludes with our final insights.

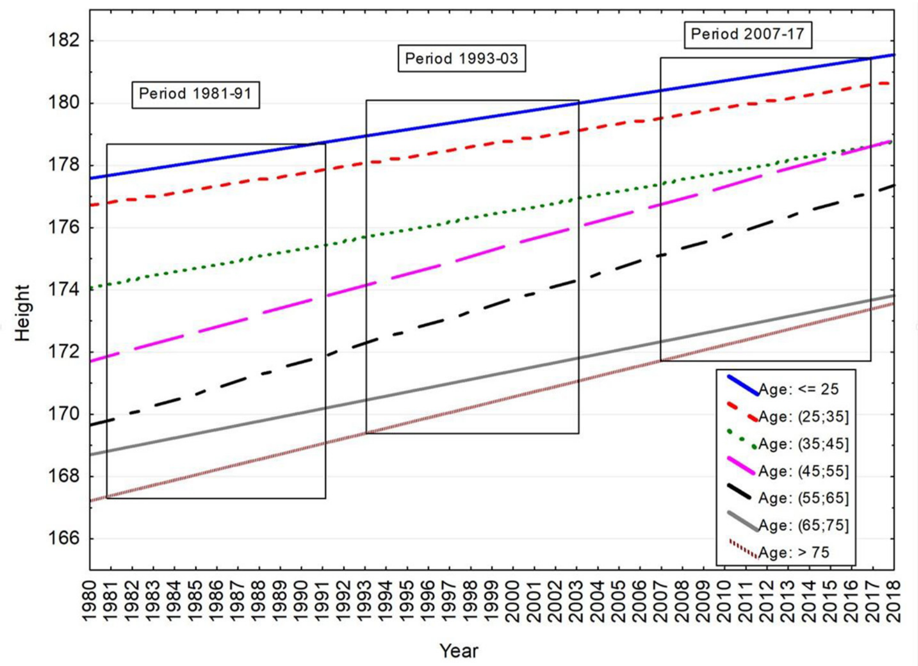
This study investigates methodologies for determining chair dimensions specifically designed for bariatric individuals with a BMI exceeding 40.

2. Material and methods

2.1 Secular trend in body mass and height based on the Slovak population

Anthropometric literature defines standardized dimensions and features for human body measurement and uses those data in design. CAD digital human models use these data for accurate representation in design processes (Dianat *et al.*, 2018). Demirel *et al.* (2022) discuss the challenge of capturing human variation in digital models, as body size changes over time (secular differences). Figure 1 depicts this trend in the growth of the Slovak population presented by Hitka *et al.* (2018).

Over the past 40 years, population height has consistently increased across all age categories (Figure 1, Table 1).



Source(s): Hitka *et al.* (2018)

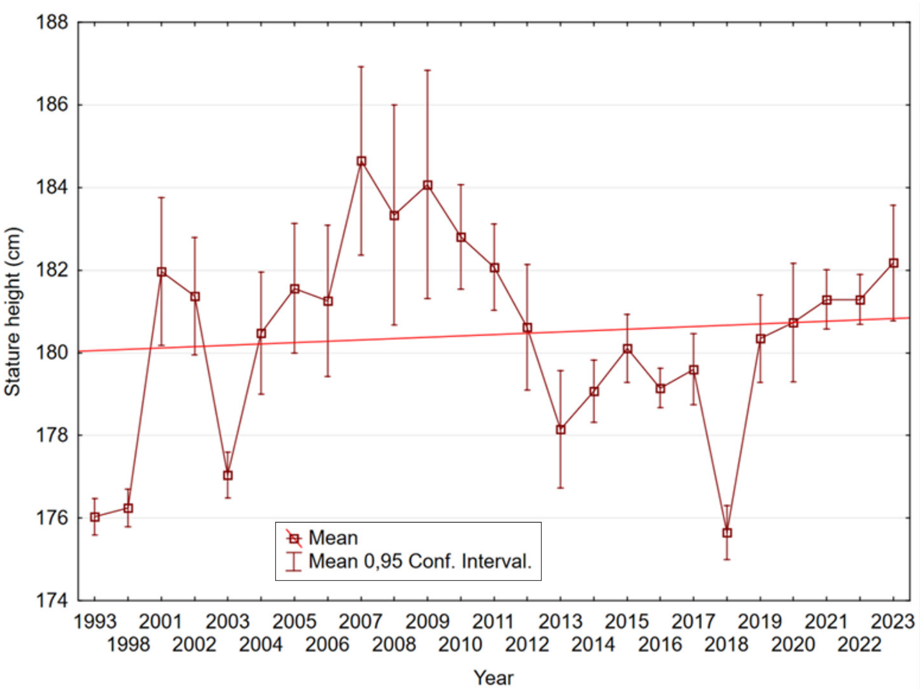
Figure 1. Secular height trends of men in different age categories and their impacts on height size in selected periods (rectangles display the three compared periods; the displayed trends for this period were obtained by backward extrapolation of linear models parametrized on measurements from 1993 to 2017)

Table 1. Secular trends in heights

Age Category	Linear regression model				Overall significance	
	Slope	SE	T	*p*-level	*F*	*p*-level
Male						
≤25	0.105	0.016	6.7339	0.00000	45.346	0.000
25–35	0.104	0.028	3.7223	0.00021	13.856	0.000
35–45	0.124	0.030	4.2035	0.00003	17.670	0.000
45–55	0.187	0.022	8.4243	0.00000	70.968	0.000
55–65	0.203	0.040	5.0723	0.00000	25.729	0.000
65–75	0.135	0.034	4.0125	0.00007	16.100	0.000
>75	0.167	0.052	3.2322	0.00138	10.447	0.001

Source(s): Authors' compilation based on (Hitka *et al.*, 2018)

Empirical measurements of the height and weight of the current male population presented in this study were carried out from 2001 to 2023 on a sample of 7,938 men aged 18–25 from the entire territory of Slovakia. Selected anthropometric dimensions were determined and we derived the body height trend for our analysis. Figure 2 illustrates the



Source(s): Authors' own elaboration

Figure 2. Stature height growth trend of men 18–25 years old in Slovakia

secular trend of the current population of men aged 18–25, while Figure 2 depicts the trend of male weight growth by age category.

Table 2 presents descriptive statistics of the data in Figure 2.

The average height of the sampled population is 178.42 cm. The range of heights spans from 158 cm to 208 cm. The percentiles offer a more granular view of the height distribution. For instance, 1% of the men are 159 cm or shorter, while 1% are 197 cm or taller. The average weight is 80.73 kg. Weights range from 52 kg to 180 kg. Similar to height, the percentiles provide valuable insight into the weight distribution. In total, 1% of the men weigh 52 kg or less, and 1% weigh 120 kg or more.

2.2 The weight of bariatric respondents

Data on the bariatric population of Slovakia, regardless of gender, were collected from medical facilities between 2020 and 2024. These data included weight, height, waist circumference, hip circumference and seat width values. Subsequently, BMI values were calculated.

Due to insufficient data, the influence of age and gender on weight was not evaluated in this study. Descriptive statistics summarizing these data are presented in Table 3.

2.3 Changing the parameters of chairs for the population with a higher weight

Data in Table 3 confirms the need for more robust seating furniture designed for heavier users. Furniture classification considers purpose, function and structure (Smardzewski, 2015). Functionality is paramount for users. Customized furniture production seems appropriate since the percentage of overweight individuals is not overwhelming. This

Table 2. Descriptive statistics of the current male population in Slovakia

n = 7,938	Arithmetic mean	Min.	Max.	SD	1st percentile	5th percentile	50th percentile	95th percentile	99th percentile
Stature height (cm)	178.42	158	208.00	8.25	159.00	165.00	178.00	191.00	197.00
Body weight (kg)	80.73	52	180.00	14.10	52.00	60.00	80.00	105.00	120.00

Source(s): Authors' compilation

Table 3. Descriptive statistics of the bariatric users in Slovakia

Parameter	*N*	Arithmetic mean	Median	Min.	Max.	Percentiles 1st	5th	50th	95th	99th	SD
Body weight (kg)	292	142.88	139.0	93.0	242.0	97.0	105.0	139.0	191.0	233.0	27.25
Stature height (cm)	292	170.84	170.0	150.0	199.0	150.0	155.0	170.0	187.0	197.0	9.27
BMI (kg/m^2)	292	48.91	47.39	35.49	89.74	36.3	38.9	47.39	64.0	76.38	7.86
Waist circumference (cm)	292	136.73	135.0	100.0	188.0	106.0	113.0	135.0	169.0	184.0	16.71
Hip circumference (cm)	292	146.6	145.0	108.0	192.0	110.0	124.0	145.0	173.0	191.0	15.28
Seat width according to the waist (cm)	292	43.56	42.9	31.85	59.87	33.76	35.98	42.9	53.82	58.60	5.32
Seat width according to hips (cm)	292	46.71	46.18	34.39	61.15	35.03	39.49	46.18	55.1	60.83	4.87

Source(s): Authors' compilation

Table 4. Dimensions in centimeters of a wooden chair for bariatric respondents

	Recommended size for percentiles				
Parameter (cm)	1st	5th	50th	95th	99th
Seat height (h_s)	49	49	49	49	49
Seat width (w)	47	50	58	67	73
Seat depth (d)	47	47	47	47	47

Source: Hitka *et al.*, 2022b

approach can accommodate diverse body types. Unlike mass-produced furniture for anonymous users, custom pieces cater to specific user needs. During production, predetermined body types based on user statistics are crucial (Kanická and Holouš, 2011). Key considerations include body weight, upper arm and thigh length in specific positions, hip width and circumference. In our case, body weight is of utmost importance. While seat height is vital, chair height, width and depth are equally crucial for optimal spinal alignment (Nag *et al.*, 2008). Sitting posture should ensure a 90-degree angle at the knees. Current recommended dimensions for a wooden chair for the general population (weight up to 110 kg) include chair height (h_0 = 1,150 mm), armrest height (h_r = 690 mm), seat height (h_s = 490 mm), seat width (w = 450 mm) and seat depth (d = 470 mm). The structural elements' cross-sections are as follows: front and rear legs 25 × 42 mm, front and rear rails, internal partitions 70 × 18 mm and footrests 25 × 42 mm (Grič *et al.*, 2017).

When determining the optimal dimensions of a wooden chair for bariatric users, we base our calculations on 95% of the dimensions of the current adult population (thigh length when sitting with a bent knee, height of the popliteal fossa) and 95% of the dimensions of bariatric respondents (seat width based on hip measurements, seat width based on waist measurements). From the data collected from bariatric respondents, we derive the width dimensions for wooden chairs (see Table 4). To ensure comfortable sitting and standing, we add an excess of 12 cm (6 cm on both sides) to the obtained dimensions of the bariatric respondents' seat width. The recommended width of the wooden chair for the 95th percentile of the bariatric population is highlighted in bold. We adhere to the currently applicable standards for furniture production regarding the height and depth of the seat (Grič *et al.*, 2017).

To ensure the chairs can safely accommodate the weight of bariatric users, they must be designed for a load-bearing capacity exceeding the 95th percentile of weight by 20%. This translates to a maximum weight capacity of 230 kg.

2.4 Identification and calculation of costs and prices of individual types of chairs

Holistic cost management and optimization increase the efficiency and flexibility of production, but their prerequisite is the correct identification, calculation and monitoring of relevant costs (Malichová *et al.*, 2016; Ďurišová *et al.*, 2019). It is essential to set a rational and competitive price for the chair according to the customer's requirements. Furthermore, it enables expanding the range of products offered, especially in small-batch production. In such cases, where quantities are low and delivery times are short, it is necessary to increase emphasis on efficiency. The traditional calculation formula comprises a list of individual types of costs, which should be supplemented with a method for quantifying these items based on calculated performance (Popesko and Papadaki, 2016). According to Macík (2008), defining a universal calculation formula for all products is problematic, as companies compile formulas adapted to their specific conditions. Various methods for developing the calculation formula are presented in literature sources, such as those by Poniščiaková (2010) and Král (2018). According to Hradecký *et al.* (2008), this typical calculation formula is the starting point for constructing formulas for different conditions.

Among the essential product features affecting its production costs are the materials used (e.g. quantity and price of wood) and the type of chair (standard or bariatric). The preliminary calculation of chair production becomes complex when considering the possibility of producing chairs with altered dimensions. To maintain profitability, companies must prioritize cost-effectiveness when determining each chair type's minimum production and sales volume. This means carefully analyzing production costs to identify the optimal number of chairs to be manufactured and sold. Costs immediately incurred and associated solely with a specific task are primarily influenced by the amount of material consumed (wood) and the time required for processing. In our model case, the performance of producing chairs for bariatric customers occurs within the framework of standard chair production. At the same time, the company is obligated to preserve economic resource utilization and profit margins.

Due to the varying dimensions of the chairs, the division calculation method cannot be used. Instead, calculation by schedule, i.e. partial calculation of direct costs using scheduling keys and methods, can be used in heterogeneous production or tasks involving shared resources. Indirect costs represent expenses incurred in support, service and management of production processes, product distribution and overall company management. Schedule bases for overhead costs can be valued based on the volume of direct costs, direct material or direct wages or in-kind based on material consumption weight or standard hours. Determining the schedule base in monetary value necessitates calculating an overhead markup as a percentage or overhead coefficient expressed as a ratio number. Formula (1) illustrates the percentage or portion of the total schedule base value of the company's overhead costs. Individual calculations then take this form:

$$S_c = S_{pr} \times \left(1 + k_r^{pr}\right) + S_{spol} \tag{1}$$

where S is the calculation rate (unit cost), index pr – direct, $spol$ – common (excluding overhead costs) and k is the coefficient of overhead costs r (Buček, 1999).

In the model case, the production procedure for chairs and the production time for standard or bariatric chairs in the individual phases of production remain unchanged. There is no need to change or modify production tools and equipment to produce bariatric chairs. There is also no need to purchase new working machines. Changing the dimensions of the chairs will only slightly affect the amount of work required to produce a bariatric chair. Production of both standard and bariatric chairs coincides under the same conditions.

In light of the described circumstances, the "Calculation by Schedule" method was used in our analysis. This method is suitable for allocating costs when different products, such as standard and bariatric chairs, are produced using shared resources within the same production environment.

3. Results

The current load capacity of the chairs is rated at 110 kg, varying depending on the type and construction. Based on the research by Hitka *et al.* (2024), we observe a linear increase in the strength of beech material. Identifying direct costs in costing is associated with consumption and time standards based on technical-economic documentation of material usage. For constructions, we consider the material characteristics of beech wood with a 684 kg/m³ density. The price of carpentry lumber has risen sharply in recent years due to inflation and increasing energy prices. The purchase price of beech wood with a thickness of 50 mm and quality A is EUR 630/m³ without a consumption tax added to the price of the final products (PS Wood, s.r.o. Dataset, 2024). The basic structure of the chair consists of front and back legs connected by pin-glued joints, with footrests on the sides of the chair (Smardzewski, 2015; Sydor and Hitka, 2023). The bariatric chair features reinforced armrests and a 170 mm wider seat compared to the standard chair (Table 5 and Figure 3). The strengths of such a chair were analyzed in the works of (Hitka *et al.*, 2022a, 2022b).

The production of standard wooden chairs begins with shaping the individual chair components according to the design specifications. Cost-performance analysis, combined with practical techniques for task-based costing, allows for cost expression based on production volume sensitivity. We distinguish between fixed costs (F_C), which do not change with production volume and variable costs (V_C), which change proportionally or nonproportionally depending on the production volume.

Based on the company's management accounting documents, we calculated the wood consumption to be 0.028 m³ per standard chair when determining direct costs. With the increased seat width and added armrests for the bariatric chair, wood consumption rose to 0.029 m³ of beech wood. Additionally, direct costs include the costs of connecting materials (screws, washers, etc.) at a fixed value of €0.57 per piece for both alternatives. Direct wages were determined based on actual labor requirements, assessed by the manufacturer as 0.52 normalized hours (NH) for the standard chair. Due to additional operations required by its construction, labor requirements increased to 0.71 NH per piece for the bariatric chairs. Other direct costs remained unchanged at €0.86 per piece for each chair type. Furthermore, when calculating the surcharge in Table 6, different schedule bases were used for individual overheads (production, supply, administration and sales). The basis for these costs was the value of direct costs (set at 100%).

The overhead costs associated with production include technological overhead (€3.50 per unit of the product), nontechnological overhead (10% of direct material costs), procurement

Table 5. Basic geometric dimensions in millimeters of the chair structure

Basic dimensions of chair frames	Standard		Bariatric
Chair height h_0		1,150	
Seat width w	500		670
Seat depth d		470	
Seat height h_s		490	
Height of armrests h_{ar}	–		690
Height of footrest mounting – rear leg h_1	160		160
Height of footrest mounting – front leg h_2	160		160

Source(s): Authors' own elaboration

Structural element	Cross-section dimensions (mm)		Structural element	Cross-section dimensions (mm)	
Front and back legs	42×25		backrest	70×18	
Armrests			Front, back, and side rails of the chair		
Footrests					

Source(s): Authors' own elaboration

Figure 3. Cross-sections of individual elements of the structure of chair frames

Table 6. Calculation of costs and prices for standard and bariatric chairs in € (year 2024)

Cost items of chairs	Standard Measurement units		€	Bariatric Measurement units		€
Direct (unit) costs						
Variable	0.028	m^3	17.64	0.029	m^3	18.27
Fixed		€/pc	0.57	pc	€/pc	0.57
Direct wages	0.52	NH/pc	2.24	0.71	NH/pc	3.06
Other direct costs		€/pc	0.86		€/pc	0.86
Direct costs total			21.31			22.76
Acquisition overhead costs			18.21			18.84
Production overhead						
Technological	3.5	NH/pc	0.27	3.5	NH/pc	0.37
Nontechnological	10	%	1.76	50	%	1.53
Production overhead			41.55			43.50
Administrative overhead costs/proper management	50	%	20.78	60	%	26.10
Performance costs			62.33			69.60
Sales overhead	20	%	12.47	20	%	13.92
Full own cost of performance			74.79			83.52
Profit (15%)	15	%	11.22	15	%	12.53
Chair price (without taxes)			86.01			96.05

Source(s): Authors' own elaboration

overhead (based on the combined cost of direct materials and direct labor), administrative overhead (50% of total production costs) and sales overhead (20% of total production costs).

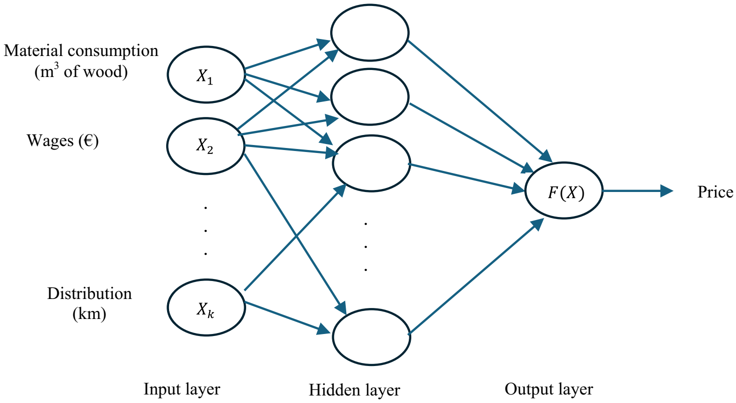
The price calculation for individual types of chairs in Table 6 indicates a 15% profit margin from completely self-performed costs, while the prices of the chairs are shown excluding taxes. Based on the above calculations, it can be concluded that the price of a bariatric chair is 11.6% higher than that of a standard chair. However, this price can still be considered competitive, given the needs it can fulfill.

To remain competitive in the market, furniture companies must have an accurate estimate of price changes and production optimization in the case of bariatric furniture production. With the increase in computing power and advances in algorithms, as in other industries, it is now possible to use machine learning (ML)-based methods such as artificial neural networks (ANN) that allow more accurate cost estimation, more flexible optimization (Verma *et al.*, 2021) and thus can be more reliable in their forecasting. In its most basic form, a neural network has only two or three layers – an input layer, a hidden layer and an output layer. Not every neuron–neuron pair has a synapse between the input and hidden layers. The output layer is the part of the neural network that makes the prediction.

It is necessary to identify the factors that most influence the costs and, consequently, the price to create such a model (Figure 4).

Developing an AI model for estimating wooden chair costs involves several steps:

- Obtaining historical or simulated data on wooden chair manufacturing costs involves material costs (including raw material prices), labor costs, transportation, distribution, marketing and other associated expenses. In this regard, using tools like the business threshold value of cost (BTVC) can aid in determining a data set for machine learning. This approach can optimize the accuracy of ML models, ultimately reducing associated costs (Table 7).



Source(s): Authors' own elaboration

Figure 4. Visualization of the structure of the model for estimating the costs and prices of chairs

Table 7. Example of how the default BTVC can be set

Direct material	Energies	Direct wages	Technology	Proper management	Sales management	Evaluation
1	1	1	1	1	1	Excellent
0	0	0	0	0	0	Neutral
−1	−1	−1	−1	−1	−1	Highly risky

Source(s): Authors' own elaboration

BTVC can consist of several k-tuples (mathematical objects), for example, on an evaluation scale ranging from −6 to +6, depending on whether it is exceptional, outstanding, very good, good, satisfactory, acceptable, neutral, slight, slightly weak, weak, risky and hazardous. The company can set the value of BTVC in decimal numbers from −1 to +1 or use any range of threshold values as needed. A greater number of possible BTVC k-tuples for ML learning leads to increased model accuracy. Of course, if we want to expand this to profit optimization, other parameters are also important, such as data on revenues from various types of chairs (standard, bariatric) and prices of each type of chair. The advantage of using ML is the ability to model many parameters that influence costs, even those with a more qualitative character. Another advantage is the identification of the most important parameters influencing costs, which subsequently also affect the price:

- Cleaning and editing the data is vital to make it suitable for the model. This may include removing missing values, normalizing data and eliminating meaningless records. Identifying relevant features or characteristics that affect the cost of making a chair, such as size, type of wood, level of detail and manufacturing technologies. Likewise, it is important to identify relationships between these parameters (in the case of profit optimization, also identifying relationships between production costs, sales, price and sales of individual types of chairs). Once the data is cleaned and modified, it is necessary to divide it into training data (used for model development) and testing data (used for measuring model performance).

- Creating an artificial intelligence model that can estimate costs based on selected functions, emphasizing achieving unchanged or optimized company profit, is essential. This model can be based on ML methods, such as linear or logistic regression, decision trees and nearest neighbor ML algorithms. For example, decision trees are constructed using a scoring function at the most basic level. This function takes inputs about the current state of the problem and assigns a score to each possible action. The action with the highest score is the one that should be taken. The scoring function can have the following form: $F(X) = w_1X_1 + w_2X_2 + \ldots + w_kX_k$, where X_1, X_2, …, X_k, are variables describing the current state of the problem and w_1, w_2,…,w_k, are the weights assigned to the variables that indicate their relative importance.
- Training the model based on data is a repetitive activity aimed at achieving maximum transferability of cost prediction, although perfect accuracy cannot be expected initially. However, the model's characteristics can be adjusted to enhance performance, and it is possible to identify breakpoints in parameter behavior, thereby increasing estimate accuracy by 30 to 40% compared to traditional methods.
- Verifying the model's performance using test data and evaluating its accuracy and reliability are essential. The model should be adapted and optimized to achieve the best possible performance. AI-powered ML can continuously monitor changes and adjust cost strategies in real time, ensuring that a business remains competitive and profitable in a dynamic environment. Random nesting is a simple and often-used method for testing neural network models, as it focuses on the dynamics, size and structure of neuronal systems rather than on the exact morphology of individual neurons. It is ideal for networks of any size, including those of varying or higher complexity, such as cost information processing models.
- Implementing the model in a natural environment involves using it to estimate the costs of wooden standard and bariatric chairs. It also includes real-time chair inventory management and price prediction based on current market conditions and demand. In this regard, the feedback from the company's managers and their expert views on the practical applicability of the model are essential.
- Regular updating and evaluation based on new data and changing market conditions are crucial. The quality and quantity of data, along with the demand for new cost estimation models using an artificial neural network (ANN), contribute to greater accuracy in cost estimation. Subsequently, software support based on dashboards facilitates a more informed decision-making process by managers (Teplická *et al.*, 2020).

The resultant pricing and, consequently, the accuracy of any price estimation are significantly influenced by fluctuations in consumption taxes levied on the final products, as well as by the prevailing rate of inflation.

A critical element is the company's strategic approach, which aims not only to achieve or sustain a profitable margin but also to develop inclusive and environmentally sustainable products in line with the objectives of sustainable development.

While various guidelines emphasize that furniture in both public and private spaces should accommodate individuals of higher weight without causing segregation or drawing attention to them, the reality remains that the bariatric population appreciates the opportunity to sit on a sturdy chair without apprehension. Within the context of typical use, design and aesthetics take a backseat for these individuals. Design and aesthetic considerations can be addressed if the individual has a personal interest in them for private use, although this significantly increases the cost. Our focus has been on establishing a pricing structure for bariatric devices that prioritizes usability and ergonomic support.

Revenue diversification within the furniture manufacturing sector ensures consistent income streams. This approach may involve broadening product offerings, targeting new market segments or providing ancillary services such as interior design consultation or furniture maintenance.

Regarding the financial implications of producing furniture for the bariatric population, it is important to note that the primary raw materials – wood, fabrics, foam and hardware components like screws, hinges and fasteners – exhibit significant cost variability. This variability is influenced by the quantity required, quality considerations and market fluctuations. By optimizing production methodologies, minimizing waste and enhancing operational efficiency, we can improve satisfaction for both supply and demand stakeholders. This could encompass initiatives such as:

- utilization of sustainable materials and the diversification of the supplier base to alleviate risks associated with shortages of raw materials and fluctuations in costs;
- the application of automation and digital technologies, the implementation of lean manufacturing principles and the integration of energy-efficient practices in wood manufacturing have a substantial impact on production costs; and
- crafting effective online marketing strategies is essential for engaging a wider audience and building a strong digital presence. The furniture sector has experienced a transformation, with an increasing number of companies transitioning to online platforms. These businesses are incorporating artificial intelligence and virtual reality technologies to enable customers to visualize how tailored furniture is integrated into their living spaces before making a purchase, thus minimizing return rates and enhancing overall customer satisfaction.

4. Discussion and conclusion

The design of furniture of all types, seating, sleeping or lying, entertainment, tables, storage and additional pieces, must be directly related to the dimensions and weight of the current and future population. Anthropological and ergonomic requirements determine the shape, dimensions and quality of the furniture and materials used. The increasing body dimensions of today's population, which, according to research by Meng *et al.* (2023), are still undergoing a significant upward trend, are crucial for ensuring correct design. Updated population data reflect the actual situation and allow the design of an optimal working environment necessary to achieve maximum employee performance while adhering to all occupational safety and hygiene principles.

The price of consumer furniture products is closely related to the material's renewability due to the energy demand of its processing. The material conditions affecting the price best suit wood (Klement and Huráková, 2016) because it is an entirely renewable raw material. Wood, as a material, is suitable for use in furniture production due to the unique harmony of its aesthetic and technical-technological properties, such as machinability, strength, low energy processing requirements and quickly processed waste. In connection with the knowledge of the secular trend of the growth of the adult population, it is necessary for companies producing furniture to adjust the calculation procedures of price formation in those areas where the causal relationship between the costs incurred and the relevant performance is expressed (Barroso *et al.*, 2005). It is also essential to adjust the product's price accordingly for products where it is necessary to change the functional dimensions of consumer furniture.

Since the calculation formula represents an inventory of individual types of costs, it should be supplemented with a method of quantifying items related to the calculated performance (Popesko and Papadaki, 2016). Innovative products, including wood plastic composite, point to the potential of using the principles of the circular economy. The increasing share of plastic waste combined with wood raw material creates great potential for meeting the environmental criteria of wood plastic composite products (Antal *et al.*, 2023). The increase in price in specific cases, depending on the labor involved in the production, can range from 5% of the cost (in the case of increased door openings) to 40% (for bed furniture) (Potkány *et al.*, 2017).

The changing anthropometric dimensions of the population create a demand from customers for new nonstandard chairs on the market. This niche market allows businesses to reach a new customer segment. However, transitioning from producing a standard type of chair to the flexible production of different chairs within established business processes requires identifying costs and subsequent calculations. Nevertheless, customers' needs cannot be ignored, particularly given the statistically confirmed increase in bariatric users.

The economic consequences of changing anthropometric dimensions in the production of chairs can be observed in the emergence of new customer segments seeking to enhance their satisfaction of needs, well-being and health. This alters the possibility of chair manufacturers responding flexibly to the market. In the case of elastic demand, reducing the price of chairs can increase sales and attract more customers. Another consequence is adjusting the production program to meet changing market requirements, adopting a holistic approach to cost management and incorporating development costs into production costs. Additionally, there is a recognized benefit in addressing the health needs of bariatric respondents, who value safe and comfortable seating. Identifying indicators that bring value to the company and its stakeholders is crucial to enhancing its competitiveness (Kušnírová *et al.*, 2023). This leads to an overall increase in satisfaction levels and the establishment of sustainable and long-lasting relationships between companies and their stakeholders. However, our research has limitations, particularly regarding companies' willingness to adjust their production programs to meet customer demands and to engage in partial production to order.

Changes in human body dimensions have economic consequences for chair production. New customer segments emerge, seeking chairs that address their comfort, well-being and health needs. This challenges chair manufacturers to adapt to a changing market. Responding to these needs requires flexibility. In markets with elastic demand (price affects sales), strategically lowering chair prices can attract a broader customer base. Manufacturers may need to adjust production lines to offer a more diverse product range. This might involve batch production or customization options. Development costs for new designs should be factored into overall production costs.

Adaptive furniture within residential environments enables the bariatric population to carry out daily activities with greater ease, thus fostering independence by accommodating the physical changes of the body types. Incorporating safety features like rounded edges and nonslip surfaces can significantly reduce the risk of accidents in the home. However, the importance of inclusive furniture design extends beyond private environments. It enhances accessibility and comfort in residential settings, public spaces, workplaces and community-based facilities (Morgan *et al.*, 2024). Innovative seating solutions that cater to the bariatric population in public venues, such as parks and community centers, improve usability for everyone. Meticulously designed public furniture encourages social engagement by cultivating inviting areas where individuals can gather. Warm materials and aesthetically pleasing designs render public spaces more welcoming, encouraging longer visits and greater community interaction. Regarding workplace utilization, such designs enhance comfort, diminish fatigue and improve productivity. By addressing employees' unique requirements through inclusive design principles, organizations can instill a sense of value and appreciation, contributing to increased job satisfaction and retention rates.

Collaborations to advance the development of universally designed furniture (Null, 2014) initiate through partnerships between manufacturers and designers to create solutions that accommodate a wide array of users. By sharing insights regarding materials, ergonomics and functionality, they can create aesthetically pleasing and highly practical products. Engaging customers, particularly those from bariatric populations, in the design process through feedback sessions or codesign workshops is vital to ensure that the final products meet their specific requirements effectively. The subsequent phases may present more significant challenges, as establishing new standards for both private and public environments will require the introduction of novel regulations. Funding initiatives focused on researching the needs of the bariatric demographic, coupled with collaborations with advocacy organizations, can greatly enhance awareness of the significance of inclusive design. This heightened awareness can, in turn, stimulate demand for inclusive furniture, motivating manufacturers to prioritize the creation of universally designed products. Additionally, collaborative events such as workshops or exhibitions that highlight inclusive designs can educate the public on its advantages, as the inclusive design not only improves functionality but also promotes a more equitable society in which all individuals can prosper (D'Itria *et al.*, 2024).

In summary, there is a growing recognition of the importance of addressing the needs of bariatric users. Providing safe and comfortable seating offers a clear benefit and aligns with the focus on well-being. Identifying factors that create value for the company and its stakeholders, such as customer satisfaction and brand reputation, is crucial for long-term success (Kušnírová *et al.*, 2023). Building solid and sustainable relationships with stakeholders fosters higher overall satisfaction and strengthens market competitiveness.

This study leverages empirical data on height and weight collected from a representative sample of 7,938 Slovakian men aged 18–25 (2001–2023). Additionally, we incorporate data on Slovakia's bariatric population obtained from medical facilities (2020–2024). This data informs two key findings:

(1) By considering the 95th percentile weight among bariatric individuals and incorporating a 20% design safety factor, we establish a recommended design load capacity of 230 kg for redesigned chairs.

(2) Our research introduces a novel method for estimating production costs based on load capacity. Notably, the estimated price increase for a universally designed chair with a 230 kg capacity is only 11.6% compared to standard chairs. This suggests that accommodating bariatric users need not be an economic barrier.

The analysis of costs and pricing strategies for standard and bariatric chairs underscores the complex interplay between material attributes and production demands. A thorough identification of direct costs and a careful examination of overhead expenses highlight the necessity of precise accounting practices for competitive pricing. The variations in production costs for chairs engineered to meet the new bariatric specifications contrast with those adhering to the EN 1729 standard in several key aspects: 1. Bariatric chairs require a slightly greater volume of wood, consuming 0.029 m^3 compared to the 0.028 m^3 used for standard chairs. 2. The labor demands for producing bariatric chairs are elevated, necessitating 0.71 NH per unit, in contrast to 0.52 NH per unit for standard chairs. 3. The direct manufacturing expense for a bariatric chair is €22.76 per piece, whereas a standard chair costs €21.31 per piece. 4. Overhead expenses related to production and administrative functions also escalate for bariatric chairs, resulting in a higher overall price point 5. Consequently, the retail price of a bariatric chair is approximately 11.6% greater than that of a standard chair, reflecting the increased material and labor expenditures associated with its design. Incorporating advanced ML techniques, including an artificial neural network (ANN), presents new opportunities for improving cost estimation and operational efficiency in furniture manufacturing.

As the industry advances, continuous data analysis and iterative model enhancement are crucial in aligning production strategies with the evolving market landscape. Ultimately, these findings contribute to developing a more sustainable and adaptive manufacturing ecosystem poised to meet the varied requirements of diverse consumer demographics.

Our research has limitations. It may not fully capture the willingness of companies to adapt production programs to meet diverse customer demands. Additionally, some companies may be hesitant to move away from mass production toward models that involve smaller batch production or customization based on individual orders. Further research could explore strategies to incentivize such adaptations and identify successful business models for this evolving market landscape. Cost estimation models can be significantly improved by integrating new ML methods and leveraging cloud computing power, leading to more informed business decision-making.

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