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Research Article

Technical and economical comparison of hydraulic and traction elevators with VDI 2225 method

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ABSTRACT

The systematic approach specifies how the product design processes should be approached systematically and specifically aims to make the most appropriate conceptual design before the objective design. In line with this goal, the systematic approach explains step by step how the conceptual design process should be done. One of these steps is the evaluation of solution variations. The basis of this step; The suitability of the desired conditions, the weighting and point system according to this suitability, and the determination of the result numerically constitute. Unlike other methods, the VDI (Verein Deutscher Ingenieure) 2225 method provides a more understandable and transparent comparison of options by showing technical competence and cost status in a single diagram, S-Diagram. In this study, the step of evaluating and selecting all the options in the conceptual design before the objective design process with the VDI 2225 method was examined in detail. The elevator was used as an example. Elevators consist of two parts traction and hydraulic. Traction elevators are divided into gearless and gearbox, and hydraulic elevators are divided into direct acting and indirect acting. These elevator types have different advantages and disadvantages compared to each other. For this reason, 3 different situations were determined, and the performances of the elevators were tried to be evaluated more objectively in the study. Situations: Elevators used in residences, high-speed elevators used in business centres and freight elevators that lift heavy loads were selected. All the results are shown on one S-Diagram. In this way, both situations were compared and the differences between them were revealed. As a result, the economic and technical performance of each elevator in each case was determined using the VDI 2225 method.

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INTRODUCTION

VDI (Verein Deutscher Ingenieure) is an abbreviation for the Association of German Engineers; VDI 2225 is a technical-economical design guide, it covers in detail the technical and economic aspects necessary for practical application in design. It is evaluated out of 4 points. Evaluation criteria are classified as 4 (very good), 3 (good),

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2 (adequate), 1 (just tolerable) and 0 (unsatisfactory). The results are placed in the S-Diagram. S-Diagram: A coordinate system created with the "x" value as the abscissa, the technical value, and the "y" value, the economic value, as the ordinate, is used to summarize the graphical representation of the technical and economical evaluations. The ideal solution is determined by the coordinates x=1 and y=1 [1].

The main purpose of the elevator is to carry people or passengers between the floors to the desired stop. These different targets also lead to the change of many components of the elevators according to their intended use. For this reason, when comparing traction and hydraulic elevators, it would not be correct to determine only one situation and make the necessary comparisons on it. For the comparison to be more accurate and consistent, it is necessary to compare the subgroups of the elevator in detail according to the purpose of use.

1. Case for residential elevator: 5 stops, 300 kg and 0,63 m/s
2. Case for business centre elevator: 20 stops, 1350 kg and 3,50 m/s
3. Case for freight elevator: 2 stops, 5000 kg and 0,63 m/s

The situations and elevator types to be compared are shown in Table 1. All elevators selected for each situation cannot be used due to technical constraints or there must be important requirements for their use. To define these constraints, each section in the table is given a letter and the reasons are listed below. The schematic visual is shown in Figure 1 [2].

Table 1. Elevators and situations to compare

Types		**Case 1**	**Case 2**	**Case 3**
Traction	Gearless	*I*	*V*	*IX*
	Gearbox	*II*	*VI*	X
Hydraulic	Direct acting	*III*	*VII*	*XI*
	Indirect acting	*IV*	*VIII*	*XII*

I, II, III, IV: All cases can be used for case 1.

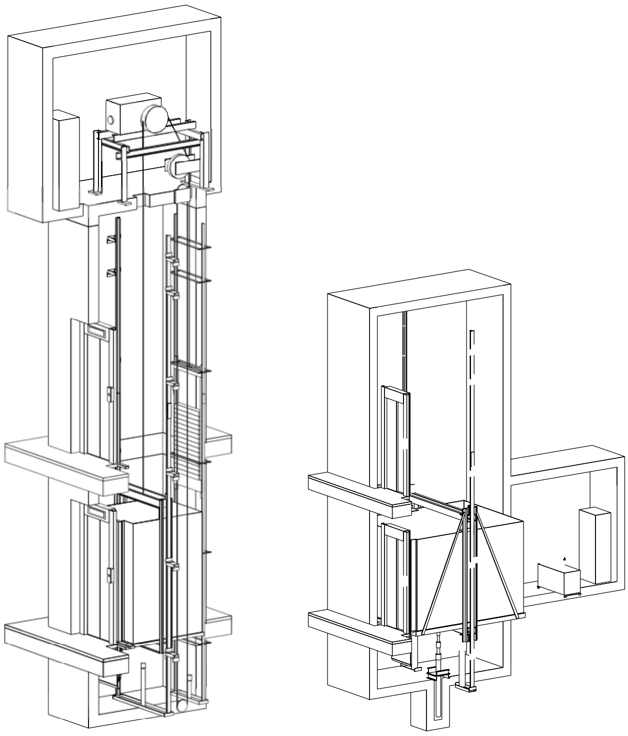
V, VI: Since the speed is selected in case 2 at more than 3 m/s^2, these elevators must use a balancing rope or chain [3].

VII, VIII: Several problems arise in hydraulic cylinders when they require longer linear motion, and therefore hydraulic elevators cannot be used for medium and high buildings. Problems: buckling can be summarized as low hydraulic system pressure and installation. Buckling is the main problem limiting the stroke length of hydraulic cylinders [4]. For this reason, it is not included in the comparison.

IX, X: 4:1 roping type is used to provide the necessary traction at a declared load of 5000 kg.

XI, XII: A piston system or a dual piston system can be used to provide the required force at a rated load of 5000 kg.

Since *I*, *V*, and *IV* are gearless, they can be applied without a machine room; since *II*, *VI*, and *X* are geared, they must have a machine room.



a) Traction Elevator b) Hydraulic Elevator

Figure 1. Elevator types.

MATERIALS AND METHODS

Technical Values

Technical evaluation: The first stage of design is used to assess the suitability of our design requirements. It is necessary to define the technical specifications by listing and combining the minimum requirements desired. A suitable solution is found only if all the fixed requirements are met. The main technical criteria are as follows: geometry, kinematics, forces, energy, material, signals, security, ergonomics, production, quality, installation, transportation, operation, maintenance, recycling, and schedules [5]. It has been examined in 12 different subjects. Assistance was received from experts and academics while scoring points in these 12 subjects.

Installation reliability

This issue was examined by the installation officers to compare the installation status of the elevator and the difficulties that may be experienced. Hydraulic elevators are easier to install than traction elevators. Because hydraulic elevators consist of fewer components. The fewer components, the simpler the installation and the less likely it is to fail or fail [6]. In addition, hydraulic elevators usually require fewer columns around the shaft because they do not apply a vertical load to the building. Especially in old building solutions, they can be used without additional construction [7]. However, unknown costs in the installation of hydraulic elevators and the exclusion of the replacement of underground systems in the maintenance contracts of the companies bring additional costs [8]. Direct acting hydraulic elevators are easier to install than indirect acting hydraulic elevators. Because indirect acting requires more equipment such as ropes, pulleys and the working system is much more complex. For this reason, it takes much longer to install [9]. Machine room elevators are easier to install than elevators without machine rooms. Because a crane is usually required to lift the traction equipment of elevators without a machine room. This makes it more difficult to set up and can create security issues. The installation time is between 4 and 6 weeks longer than the others [10]. The rating according to this information is shown in Table 2.

Table 2. Installation reliability

Types		Case 1	Case 2	Case 3
Traction	Gearless	2	0	1
	Gearbox	3	1	2
Hydraulic	Direct acting	4		4
	Indirect acting	3		3

Drive reliability

While the elevator is running, this issue has been examined to compare the problems that may occur during driving. The driving safety of hydraulic elevators is greater than traction elevators. Because there is no counterweight movement in hydraulic elevators, it is safer when working [9]. However, since the properties of the oil used in hydraulic elevators change with temperature, there may be performance changes. [8]. Even worse, if hydraulic oils are not properly maintained, deterioration and contamination of the hydraulic oil can lead to serious injuries [11]. In general, accidents have been significantly reduced by standards. Based on this information, the rating is shown in Table 3.

Table 3. Drive reliability

Types		Case 1	Case 2	Case 3
Traction	Gearless	3	2	2
	Gearbox	3	2	2
Hydraulic	Direct acting	4		3
	Indirect acting	4		3

Maintenance

All the work required to ensure the safety of the plant and its components and the fulfilment of their designed functions during the life cycle of the elevator and after the completion of its installation is called maintenance reliability [3]. This issue has been examined to compare the maintenance needs of the elevator and the problems that may occur during maintenance. Traction elevators need maintenance more than hydraulic elevators. Because they contain fewer components than traction elevators. All necessary parts are readily available [6]. Especially since there is no counterweight movement, hydraulic elevators are considered much safer during the lifetime of service and repair work [9]. Traction elevators are maintained more frequently than hydraulic elevators [12]. However, elevator related regulations do not have specific requirements for hydraulic oil, and the elevator service contract rarely touches on oil quality or acquisition; as a result, there is no mention of oil. This leads to faults in closed parts such as gaskets, valves, engines, and cylinders [13]. The maintenance need for gearless elevators is higher than for geared elevators. Because geared elevators have a larger drive than gearless ones. This requires larger tools, which complicates maintenance. In addition, gearbox drives need to be lubricated regularly. This makes maintenance more difficult and expensive. In gearless elevators, the parts are smaller and do not need oil [14]. Gearless drives are generally preferred in the shaft. The temperature and humidity conditions inside the shaft are very harmful to mechanical, and electro-mechanical equipment. Manufacturers must take sufficient care in their design to provide extra protection to equipment in such hot and humid environments, especially in hot climates. The percentage of moisture and dirt in the elevator shaft is reported as 81%. [6]. It is recommended that passenger elevators used in residential elevators (case 1) be inspected once a year, commercial passenger elevators (case 2) at least 4 times a year, the case of commercial freight elevators (case 3) are usually inspected twice a year [15]. The rating according to this information is shown in Table 4.

Table 4. Maintenance

Types		Case 1	Case 2	Case 3
Traction	Gearless	3	1	2
	Gearbox	2	0	1
Hydraulic	Direct acting	4		2
	Indirect acting	4		2

Rescue operation

The special activities carried out to safely rescue the person trapped in the car and shaft are called rescue operations [3]. This issue has been examined to compare the problems that may occur during the elevator rescue operation. The rescue operation of hydraulic elevators is easier than traction elevators. In hydraulic elevators, in case of possible failures (power failure, going through a phase, throwing a fuse) the elevator can automatically reach the floor [8]. Because there is no need for extra power to reduce the pressure in the hydraulic cylinders. However, in traction elevators, when the engine brake is neutralized, the heavy side goes down and the levelling is manual. There must be batteries (uninterruptible power supplies) inside the controller so that it can automatically come to the floor. In addition, the rescue operations of traction elevators require experienced personnel, otherwise, they can cause fatal disasters considering the above situations. Hydraulic elevators can also be performed within minutes by an informed individual [6]. Based on this information, the rating is shown in Table 5.

Table 5. Rescue operation

Types		Case 1	Case 2	Case 3
Traction	Gearless	2	2	2
	Gearbox	2	2	2
Hydraulic	Direct acting	4		4
	Indirect acting	4		4

Earthquake and fire

Additional precautions are required for the elevators to be usable in the event of an earthquake, which is described in detail in EN 81-77. Most of the measures taken against earthquakes are related to rail and rail consoles [16]. Likewise, additional precautions should be taken for elevators in the event of a fire. Most of these additions, which are described in detail in the EN 81-73 is related to doors [17]. Because the doors are expected to be fire resistant to certain degrees to prevent a fire outside from entering the shaft, however in this section the behaviour of elevators that do not have these additional measures against earthquakes and fires is examined. Hydraulic elevators are more resistant to earthquakes than traction elevators. In traction elevators, car and counterweight rails and fixings, guide assemblies are the most vulnerable. During an earthquake, the top floor shakes at a greater amplitude than the ground floor. Therefore, the installation of a drive unit and its equipment at the top of the building becomes more critical. The counterweight and car, the heaviest component of the elevator system, exert large inertial forces on the rails due to their large mass, causing damage and derailment. The most common hazards are the counterweights being stripped off their rails and swaying in the shaft and hitting the car. During the Seattle earthquake in February 2001, 11% of traction elevators and only 1% of hydraulic elevators were damaged [6]. The fire resistance of gearless elevators is less than others. In a gearless elevator, traction equipment is usually located above the shaft. Access to evacuation equipment above the building can be problematic in the event of a fire. Releasing the engine brake can cause the car to move up, not down [6]. According to this information, the rating is shown in Table 6.

Table 6. Resistance to earthquake and fire

Types		Case 1	Case 2	Case 3
Traction	Gearless	1	0	1
	Gearbox	2	0	2
Hydraulic	Direct acting	4		4
	Indirect acting	4		4

Environment

As with all products, the relationship of the elevator with the environment is undeniable in the globalizing world. From residential buildings to high-rise buildings, elevators use about 2-10% of the energy used by the entire building [18]. To compare energy use and its impact on the environment, this section has been examined as a technical criterion. The energy efficiency of traction elevators is higher than hydraulic elevators. The fact that the traction elevator is active even when on standby causes energy consumption [18]. Although the drive only works when the car is moving upwards, the energy use of hydraulic elevators is 2.5 to 3 times higher than traction elevators of the same speed and the same capacity [8]. The biggest reason for this is the use of counterweights. The purpose of using the counterweight is to use a smaller drive, by the way energy saves [9]. Traction elevators are more environmentally friendly than hydraulic elevators. Because oil leaks from underground systems of hydraulic elevators can pollute the surrounding water resources [8]. Today, biodegradable hydraulic fluids are increasingly used [19]. The energy efficiency of gearless elevators is higher than geared elevators. Because geared elevators use gearboxes, their efficiency is less than gearless elevators [14]. The gear ratio is normally chosen from 20:1 to 40:1 depending on the load and speed of the elevator. The higher the gear ratio, the lower the system efficiency will be since most of the power is consumed in the gear. [6]. The rating according to this information is shown in Table 7.

Table 7. Environment

Types		Case 1	Case 2	Case 3
Traction	Gearless	4	1	2
	Gearbox	3	0	1
Hydraulic	Direct acting	2		2
	Indirect acting	2		2

Shaft efficiency

For elevators to be installed, they need a minimum pit and headroom distance, and necessary shaft space. The main reason for these needs is related to the fit of the shaft equipment into the shaft. Elevators that are not normally possible to install can be installed by taking special precautions (buffers are folding, a balustrade is telescopic, etc.) [20]. The shaft efficiency of hydraulic elevators is higher than traction elevators. A hydraulic elevator with the same characteristics requires much less pit and headroom than a traction elevator with the same characteristics [10]. The biggest reason for this is that traction equipment is not used. If the hydraulic equipment is located outside the shaft, the number of equipment that can interfere with the elevator above and under the shaft is very small. In addition, depending on the condition of the shaft, the hydraulic cylinder can be applied to the caret in many ways [6]. In some cases, hydraulic elevators can even freely reach the terrace floor [7]. In addition, the use of a counterweight requires a certain area in the shaft. This means that the car space in the same shaft space will be different from direct hydraulic elevators and other elevators. Since the car area is directly proportional to the number of people it carries, direct hydraulic elevators in the same shaft gap may have more carrying capacity. The more complex the pulley system in traction elevators, the more likely it is to take up space in the shaft. Because pulleys and ropes need to cover a certain space to work smoothly. According to this information, the rating is shown in Table 8.

Table 8. Shaft efficiency

Types		Case 1	Case 2	Case 3
Traction	Gearless	3	3	2
	Gearbox	3	3	2
Hydraulic	Direct acting	4		4
	Indirect acting	4		3

Quantity of car doors

Depending on the structure of the buildings, the location and quantity of the car door(s) may be important. The quantity of car doors that can be used in direct acting hydraulic elevators is higher than in other elevators. In direct acting hydraulic elevators, there is no equipment such as a counterweight or hydraulic cylinder moving next to the car, so a car door can be placed on 4 sides. In indirect acting elevators, the single-cylinder elevator closes only one wall, while the double cylinder elevator closes both walls. Single cylinders can have 3 doors, and double cylinders can have 2 doors. Thanks to some special precautions (taking the cylinders to the corner of the shaft, etc.), this number can be increased, but it is not a common method. The same working logic applies to the L car frame and the M car frame. Since 3 sides of the L car frame are open, 3 doors can be placed, while in the M car frame, 2 doors can be placed mutually. The L car frame cannot be used because a more durable structure is required in freight elevators, so freight elevators can only contain 2 doors even if they are traction. The rating according to this information is shown in Table 9.

Table 9. Quantity of car doors

Types		Case 1	Case 2	Case 3
Traction	Gearless	3	3	2
	Gearbox	3	3	2
Hydraulic	Direct acting	4		4
	Indirect acting	3		2

Machine room

One of the biggest constraints is whether the elevator needs the machine room, if it needs it, the appropriate location is suitable for the structure of the buildings. Gearless elevators do not need a machine room. Gearboxes, such as worm gears and planetary gears, require the machine to be large and weigh. However, the traction pulley of a gearless machine is seated on the same axle shaft of the drive, providing a simpler way of transferring power. Gearless machines provide size and weight advantages with these features. This means that it is suitable for use without a machine room [6]. The location of the machine rooms of hydraulic elevators can be chosen more freely than for geared elevators. The machine room of traction elevators must be located inside or near the shaft. Because the movement of the car is connected to the ropes, movement can be provided by diversion pulleys from the engine to the car. The movement of hydraulic cylinders requires pressurized oil, so there is no need for it to be near or inside the shaft. Based on this information, the rating is shown in Table 10.

Table 10. Machine room

Types		Case 1	Case 2	Case 3
Traction	Gearless	4	4	4
	Gearbox	2	2	2
Hydraulic	Direct acting	3		3
	Indirect acting	3		3

Vibration

How much the car vibrates from the first movement to the stop is one factor that determines the elevator's comfort level. Impact-free start and stop, as hydraulic elevators do not have a gear system; they have stepless speed adjustment [8]. In the case of traction elevators, gearless drives offer a more vibration free driving experience than gearboxes [6]. The main reason for this is the gears in the gearbox. If the hydraulic elevator makes a sudden stop, stops between floors, has difficulty in taking a position and stops with large loads or shows similar symptoms, the elevator is experiencing problems. Transition discrepancies are caused by various oil disorders and impurities [11]. The use of oil in hydraulic elevators can affect the vibration level and reduce comfort. Based on this information, the rating is shown in Table 11.

Table 11. Vibration

Types		Case 1	Case 2	Case 3
Traction	Gearless	4	4	4
	Gearbox	3	3	3
Hydraulic	Direct acting	4		4
	Indirect acting	4		4

Sound

The sound inside the car is as important as the sound that the machine room gives out. The sound level inside the surrounding apartments and elevators is one of the factors affecting the comfort level. Since the location of the machine rooms of hydraulic elevators can be freely selected, a selected machine room further away from the shaft reduces the noise level [6]. For this reason, hydraulic elevators can work less audibly. Gearless elevators work with much less noise than geared elevators. Since there is no gearbox, the sound levels are lower in both the shaft and the machine room [14]. The sound level may be affected in residential buildings close to the machine room. The rating according to this information is shown in Table 12.

Table 12. Sound

Types		Case 1	Case 2	Case 3
Traction	Gearless	4	4	4
	Gearbox	3	3	3
Hydraulic	Direct acting	4		4
	Indirect acting	4		4

Levelling

The performance of the car standing at the level of the floor threshold on the specified floor is called levelling. Misalignment of the elevator may cause passengers to stumble or fall during the boarding and exit of the elevator. For this reason, the correct position of the car on the floor has been examined as one of the technical criteria. Lowering hydraulic elevators to the floor level of the car can be done simply in the machine room with a manual lowering button or lever. With the optional inclusion of a small hand pump, the car can also be raised to a higher floor level if necessary [6]. Hydraulic elevators have precise floor adjustment (±3 mm) and automatic levelling [8]. But the temperature can affect the performance of the oil. Extremely hot or excessively cold oil causes the viscosity to not conform to the defined parameters that determine the stop of the elevator [11]. The levelling performance of gearless elevators is much higher than geared elevators. Since there is no gearbox in between, millimetre levelling can be adjusted [14]. The rating according to this information is shown in Table 13.

Table 13. Levelling

Types		Case 1	Case 2	Case 3
Traction	Gearless	4	4	4
	Gearbox	2	2	2
Hydraulic	Direct acting	3		3
	Indirect acting	3		3

Determination of Weighting (g)

Since the criteria weights were not considered equal, the weighted average was used instead of the arithmetic average when finding the technical value. Weighting was performed by the dominance matrix [5]. For this purpose, the two criteria were directly compared with each other, and the order of importance was determined. The criteria are placed in both the row and the column and compared step by step. As a rating, 1 means that the values in the first row are more important than the values in the first column, 0.5 is equally important, and 0 is less important. However, instead of using only 0, 1 and 0.5 values, 0.25 and 0.75 values were also used to obtain a more precise distribution [21]. The weighting process according to these operations is shown in Table 14. Areas above the diagonal line are automatically calculated by counter-equity. The weighting of the comparison crickets was then calculated by dividing their vertical sum by the total score. The sum of the weights is 100%.

Determination of Technical Values

All found points and weightings were used to calculate the weighted technical value (x_g). The technical value can be calculated as [1]:

$$x_g = \frac{p_1 \times g_1 + p_2 \times g_2 + p_3 \times g_3 + \ldots + p_n \times g_n}{(g_1 + g_2 + g_3 + \ldots + g_n) \times p_{max}} \quad (1)$$

The equation can also be written as below:

$$x_g = \frac{p_{gtotal}}{(g_1 + g_2 + g_3 + \ldots + g_n) \times p_{max}} \quad (2)$$

Table 14. Weighting score

	A	B	C	D	E	F	G	H	I	J	K	L
A		0.75	0.25	0	0	0.5	0	0	0	0	0	0
B	0.25		0	0	0	0.25	0	0	0	0	0	0
C	0.75	1		0.25	0	0.75	0	0	0	0	0	0
D	1	1	0.75		0	1	0	0	0	0	0	0
E	1	1	1	1		1	0	0	0	0	0	0
F	0.5	0.75	0.25	0	0		0	0	0	0	0	0
G	1	1	1	1	1	1		0.25	0.5	0.75	0.75	0.25
H	1	1	1	1	1	1	0.75		0.75	1	1	0.5
I	1	1	1	1	1	1	0.5	0.25		0.75	0.75	0.25
J	1	1	1	1	1	1	0.25	0	0.25		0.5	0
K	1	1	1	1	1	1	0.25	0	0.25	0.5		0
L	1	1	1	1	1	1	0.75	0.5	0.75	1	1	
Total	9.5	10.5	8.25	7.25	6	9.5	2.5	1	2.5	4	4	1
g	14.4%	15.9%	12.5%	11.0%	9.1%	14.4%	3.8%	1.5%	3.8%	6.1%	6.1%	1.5%

$$p_{gtotal} = p_{g1} + p_{g2} + p_{g3} + \ldots + p_{gn} \quad (3)$$

$$p_g = g \times p \quad (4)$$

In this study, the sum of all weights is 1 and the maximum point that can be given is 4.

$$x_g = \frac{p_{gtotal}}{1 \times 4} = \frac{p_{gtotal}}{4} \quad (5)$$

Gearless traction case 1 (*I*) is examined as an example. The weighted point score for installation reliability can be calculated as:

$$p_{g1} = p_1 \times g_1 = 0{,}144 \times 2 = 0{,}29 \quad (6)$$

All criteria's score and the technical value can be calculated as:

$$p_{gtotal} = 0{,}29 + 0{,}48 + 0{,}38 + 0{,}22 + 0{,}09 + 0{,}58 + 0{,}11 + 0{,}05 + 0{,}15 + 0{,}24 + 0{,}24 + 0{,}06 = 2{,}88 \quad (7)$$

$$x_g = \frac{2{,}88}{4} = 0{,}721 \quad (8)$$

All results are shown in Table 15.

Table 15. Technical value

		Traction												Hydraulic							
		Gearless						Gearbox						Direct Acting				Indirect Acting			
		Case 1		Case 2		Case 3		Case 1		Case 2		Case 3		Case 1		Case 3		Case 1		Case 3	
		I		*V*		*IV*		*II*		*VI*		*V*		*III*		*VI*		*IV*		*VII*	
	g	p	p_g	p	p_g	p	p_g	p	p_g	p	p_g	p	p_g	p	p_g	p	p_g	p	p_g	p	p_g
A	14.4%	2	0.29	0	0.00	1	0.14	3	0.43	1	0.14	2	0.29	3	0.43	4	0.58	3	0.43	4	0.58
B	15.9%	3	0.48	2	0.32	2	0.32	3	0.48	2	0.32	2	0.32	4	0.64	3	0.48	4	0.64	3	0.48
C	12.5%	3	0.38	1	0.13	2	0.25	2	0.25	0	0.00	1	0.13	4	0.50	2	0.25	4	0.50	2	0.25
D	11.0%	2	0.22	2	0.22	2	0.22	2	0.22	2	0.22	2	0.22	4	0.44	4	0.44	4	0.44	4	0.44
E	9.1%	1	0.09	0	0.00	1	0.09	2	0.18	0	0.00	2	0.18	4	0.36	4	0.36	4	0.36	4	0.36
F	14.4%	4	0.58	1	0.14	2	0.29	3	0.43	0	0.00	1	0.14	2	0.29	2	0.29	2	0.29	2	0.29
G	3.8%	3	0.11	3	0.11	2	0.08	3	0.11	3	0.11	2	0.08	4	0.15	4	0.15	4	0.15	3	0.11
H	1.5%	3	0.05	3	0.05	2	0.03	3	0.05	3	0.05	2	0.03	4	0.06	4	0.06	3	0.05	2	0.03
I	3.8%	4	0.15	4	0.15	4	0.15	2	0.08	2	0.08	2	0.08	3	0.11	3	0.11	3	0.11	3	0.11
J	6.1%	4	0.24	4	0.24	4	0.24	3	0.18	3	0.18	3	0.18	4	0.24	4	0.24	4	0.24	4	0.24
K	6.1%	4	0.24	4	0.24	4	0.24	3	0.18	3	0.18	3	0.18	4	0.24	4	0.24	4	0.24	4	0.24
L	1.5%	4	0.06	4	0.06	4	0.06	2	0.03	2	0.03	2	0.03	3	0.05	3	0.05	3	0.05	3	0.05
p_{gtotal}	100%	2.88		1.66		2.11		2.62		1.31		1.85		3.52		3.25		3.50		3.18	
x_g		0.721		0.416		0.528		0.655		0.328		0.463		0.879		0.813		0.875		0.795	

Table 16. Economic value

Rated load	300 kg				1350 kg		5000 kg			
Car mass	500 kg				1300 kg		3000 kg			
Distance	12m				57m		3m			
Rated speed	0.63m/s				3.5m/s		0.63m/s			
Type	**Traction**		**Hydraulic**		**Traction**		**Traction**		**Hydraulic**	
	Gearless	**Gearbox**	**Direct**	**Indirect**	**Gearless**	**Gearbox**	**Gearless**	**Gearbox**	**Direct**	**Indirect**
	I	***V***	***IV***	***II***	***VI***	***V***	***III***	***VI***	***IV***	***VII***
Car	1.000 €				2.000 €		2.500 €			
Car frame	1.500 €				2.000 €		2.000 €			
Landing door	250 € x5 = 1.000 €				350 € x20 = 7.000 €		500 € x2 = 1000 €			
Car door	500 €				700 €		900 €			
Pit equipments	500 €				800 €		800 €			
Controller	3.500 €				3.500 €		3.500 €			
Car guide rail	T90/A				T140-1/BE		T140-2/B			
	24 €/m x 24m = 576 €				35 €/m x 114m = 3990 €		37 €/m x 6m = 222 €			
Car guide rail bracket	10 € x 24 = 240 €		6 € x 24 = 144 €		15 € x 114 = 1710 €		20 € x 6 = 120 €		15 € x 6 = 90 €	
Drive	1.2kW		6.5kW		31kW		18.5kW		65kW	
	2.000 €	1.500 €	500 €		5.000 €	4.500 €	3.500 €	3.000 €	4.000 €	
Machine frame	400 €	200 €	-	-	500 €		700 €		-	-
CW guide rail	T70/A		-	-	T140-1/BE		T89/A		-	-
	18 €/mx24m = 432 €		-	-	35 €/mx114m = 3.990 €		23 €/mx6m = 138 €		-	-
CW	1.000 €		-	-	2.000 €		2.000 €		-	-
Governor	400 €		-	-	400 €		400 €		-	-
Roping	1:1		-	-	2:1		4:1		-	-
Rope	6.5mm		-	6.5mm	6.5mm		8mm		-	8mm
	1 €/m		-	1 €/m	1 €/m		1.2 €/m		-	1.2 €/m
Quantity of rope	5		-	5	8		8		-	8
Length of rope	15x5 =75m		-	8x5 = 40m	128x8 = 1024m		45x8 = 360m		-	3x8 = 24m
Compensation	-		-	-	50%	-	-	-	-	-
Rope	75 €		-	40 €	1.536 €		432 €		-	29 €
1. Cylinder diameter	-	-	100mm	90mm	-	-	-	-	150mm	2x180mm
1. Cylinder thickness	-	-	10mm	12mm	-	-	-	-	10mm	10mm
2. Cylinder diameter	-	-	140mm	-	-	-	-	-	-	-
2. Cylinder thickness	-	-	10mm	-	-	-	-	-	-	-
3. Cylinder diameter	-	-	200mm	-	-	-	-	-	-	-
3. Cylinder thickness	-	-	15mm	-	-	-	-	-	-	-
Hydraulic lifting unit	-	-	2.000 €	500 €	-	-	-	-	950 €	1.900 €
Hydraulic tank	-	-	220 l	80 l	-	-	-	-	60 l	160 l
	-	-	880 €	320 €	-	-	-	-	240 €	640 €
Total	13.123 €	12.423 €	12.532 €	10.512 €	34.526 €	34.026 €	18.212 €	17.812 €	16.634 €	18.013 €
y	0.797	0.814	0.812	0.862	0.262	0.274	0.670	0.680	0.709	0.675

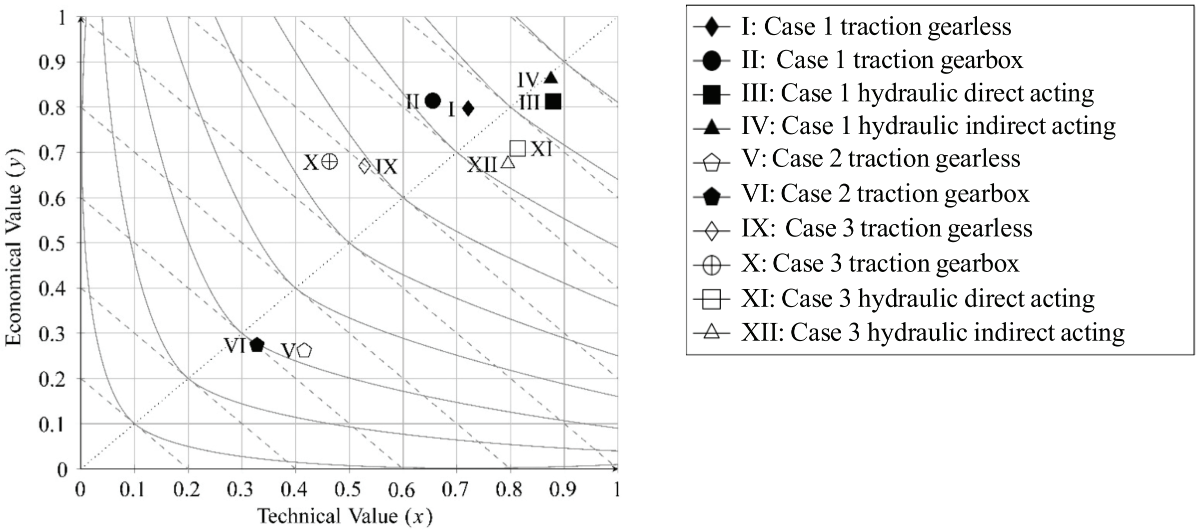


Figure 2. S- diagram.

Determination of Economic Values

VDI 2225 proposes to use the cost of production as the only criterion for economic evaluation. The appropriate rating was made based on the studies on elevator prices. These ratings consist of only one approach, costs vary depending on countries and companies. Opinions were received from global elevator companies and sector representatives for equipment prices and the average was taken. Approximate prices and economic values (y) based on the above studies and market data are shown in Table 16. In the table, the case where the economic value is 1 is 5,000 € and the situation where 0 is 45.000 €.

RESULTS AND DISCUSSION

The technical and economic values are shown in the S-Diagram shown in Figure 2. The purpose of showing it in a single diagram is not only to make comparisons within situations but also to make comparisons between situations.

The results based on these values are listed below.

- In general, the difference between the first cases in the table is noticeable. Case 1; the residential elevator, has the closest values to 1 economically and technically. In contrast, the high-speed business centre elevator has values closest to 0. Technically, when we compare a residential elevator with a high-speed and high-speed elevator, the residential elevator will be easier to install, easier to maintain, and less malfunctioning; it was investigated when rating that it would be less costly economically. This table has led to a more visual understanding of the results.
- When case 1 is examined, it is observed that hydraulic elevators shown by points III and IV are technically better than traction elevators shown by I and II, although not much difference economically. There is no serious difference between being in direct acting and indirect acting. As a result, it can be inferred that hydraulic elevators are more advantageous in residential elevators used at low speeds and low rated loads.
- When case 2 is examined, there is not much economic difference between the traction elevators shown by points V and VI. Because of the price of the engine in high-rise buildings; The guide rail will have a smaller proportion as the quantity of guide rail fixings and floor doors increases. However, it can be observed that the gearless elevator is technically more advantageous than the geared elevator. As a result, since hydraulic elevators are not suitable for high-rise buildings, it can be inferred that gearless elevators are more advantageous in elevators used at high speeds and high distances.
- For case 3, the traction elevators shown by points IX and X appear to be technically inadequate, although not much difference economically compared to the hydraulic elevators shown by points XI and XII. Although hydraulic elevators are technically no different, direct acting is economically more advantageous. The main reason for this is that to 2 stops building, direct acting is more feasible. As a result, it can be inferred that direct acting elevators are more advantageous in elevators used in heavy loads.
- If all situations are evaluated for geared and gearless elevators, it can be observed that geared elevators have a higher score economically and gearless elevators have a technically higher score. However, for all cases, we see that gearless elevators are closer to an upper parabolic line than geared elevators. As a result, it will be more appropriate to choose gearless elevators.

CONCLUSION

The VDI 2225 method provides a more understandable and transparent comparison of options by showing technical competence and cost status in a single diagram, S-Diagram. S-Diagram: A coordinate system created with the "x" value as the abscissa, the technical value, and the "y" value, the economic value, as the ordinate, is used to summarize the graphical representation of the technical and economical evaluations. The evaluation of the VDI 2225 method used in this study is listed below.

- It has been observed that it is very useful when comparing the results as it can present the results both technically and economically. In this way, which aspect of the design or the compared situation can be revealed as strong and which direction is weak?
- 4 points method is more suitable for superficial comparisons or if there are too many comparison criteria. For more detailed comparisons, the evaluation over 10 points will be more accurate.
- The VDI 2225 method states that all criteria have the same weighting and that weighting should not be used unless it is necessary. However, the ease of installation and the same weighting of the quantity of car doors for this work means that there cannot be an accurate comparison. For this reason, weighting was used to determine the technical values.
- The VDI 2225 proposes to use the cost of production as the only criterion for economical evaluation. For this reason, economic evaluation remains uniform. The study of some criteria in economic value instead of technical value may make the evaluation more appropriate.

In this study, the VDI 2225 method was examined, and the elevator was used as an example. It is suitable for use in mechanical systems. For future studies, this study can be done with the Pahl & Beitz Method and the differences between VDI 2225 can be evaluated.

NOMENCLATURE

g Weighting score
x_g Weighted technical value
x Technical value
y Economical value
p Point score
p_g Weighted point score

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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