

Total Cost of Ownership as an Effective Method of Calculating the Total Cost of in vitro Laboratory Equipment

Mamaloukas B. Dionysios¹, Tzavaras E. Panagiotis²

¹ Biomedical Engineer, Greece

² European University of Cyprus, Greece

Abstract

The TCO - total cost of ownership - methodology, which is also the subject of research, provides the laboratory in vitro manager with a structured approach to analyzing all direct and indirect costs associated with selection of in vitro biomedical equipment, allowing comparative, documented acquisition of decisions based on laboratory costs, while ensuring high quality test results and competitive advantage to a rapidly changing economic and health environment. Reference is made to literature review research studies aimed at highlighting the benefits arising from the adoption of philosophy of the evidence-based Total Cost of Ownership (TCO) approach. Additionally, personal specialized research was conducted regarding the selection of an in vitro diagnostic analytical platform and the total cost it produces throughout its lifetime. A questionnaire in electronic format was used in order to detect the preferences of healthcare professionals working in either public biopathology laboratories or private health care organizations or pharmaceutical diagnostic companies towards the total cost of ownership. The results of the research are particularly encouraging for TCO since the managements of the laboratories consider that is the strategic approach to the selection of biomedical equipment and an important factor for the sustainability of in vitro laboratories.

Keywords: LOS, maintenance, TAT, TCO, turnaround

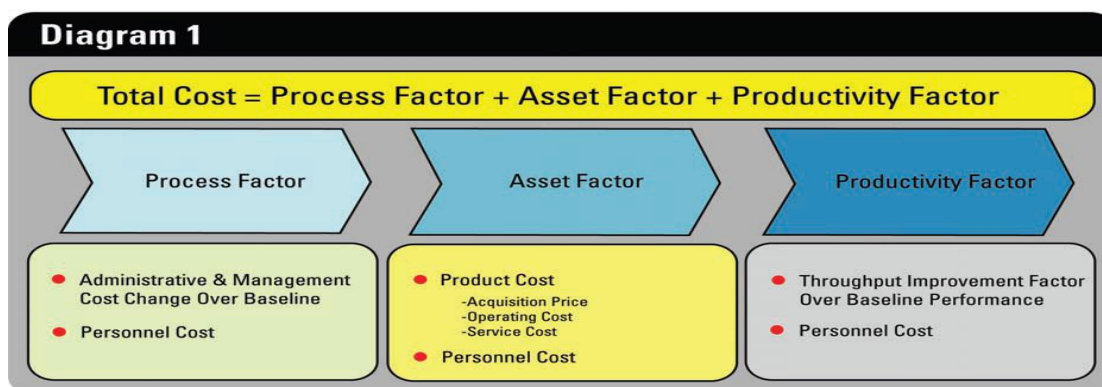
1. Introduction

The process of evaluating and acquiring technology must be carried out with clear, fair and comprehensive criteria. The following elements are part of the criteria: compliance with technical characteristics, compliance with after-sales agreements or conditions, analysis and compliance with economic conditions throughout the life cycle of the technology, and analysis related to economic and financial forecasts regarding the technology to be acquired (Hernández, A. et. al , 2010). The total cost of ownership methodology approach is proven to be more effective compared to the conventional analytical platform procurement approach as it enables the practice of evidence-based strategic management and technology procurement decisions and enables laboratories to create financial dashboards, facilitating future resource allocation exercises and laboratory budget.

Factors that contribute to the definition of TCO concern the process, the product, the productivity (Figure 1). These factors are related to the direct and indirect costs in each phase of the life cycle of the biomedical equipment. Thinking in these TCO terms should contribute to a better understanding of all costs associated with the acquisition, operation, maintenance and disposal of analytical systems (Martinko,2010).

Figure 1.

Factors contributing to TCO



Source: Martinko-Thermo fischer scientific, 2010

1.1 Process Factor

The additional costs associated with insufficient processes are extremely difficult to be measured resulting in a complete lack of visibility into lost revenue. In this case, projects take longer to complete, additional resources are allocated to support them, a non-merit distribution of workload among staff is observed, and initiatives and activities are re-prioritized with a negative effect on the total cost of ownership (Table 1).

A careful look at the acquisition process is required, including acquisition costs, payment terms, inventory holding and unit price (Martinko,2010). It is a necessity to implement a process to manage the life cycle of laboratory equipment.

Table 1.

Costs related to the management of biomedical equipment ownership processes

Process Factor (Costs related to managing and administering equipment & instrument ownership processes)			
Acquisition	Operation	Maintenance	Disposition
Needs Assessment	Continuing Education	Service Request Management	Redeployment
Planning & Budgeting	Inventory / Information Management	Service Event (PM) Management	Liquidation
Vendor Selection (RFP)	Compliance	Documentation Management	Disposal
Financing	Consumables Management	Data Management	Waste Management
Implementation / Training	Asset Tracking / Utilization	Retirement Management	Donation
Strategic Sourcing	Department Management	Engineering / IT / Facilities	Facilities
Enterprise Asset & Service Management System Costs - Software, Hardware, Implementation and Support			

Source: Martinko-Thermo fischer scientific, 2010

1.2 Product Factor

The product factor is mainly related to direct costs and becomes easier to quantify because it is usually included in the budget. It concerns the pricing of the analytical platform, the reagents and consumables necessary for its operation, the practical working time consumed by the laboratory staff and the costing of services. The secondary indirect cost is the cost of the laboratory staff, who manage the equipment (Table 2).

Table 2. Costs related to owning instruments and equipment

Product Factor (Costs related to owning instruments & equipment)			
Acquisition	Operation	Maintenance	Disposition
Equipment Purchase Price	Education / Training Costs	Cost of Repairs	Cost of Disposal
Financing Costs	Accessories	Cost of Preventative Maintenance	Storage Costs
Installation Costs	Consumables	Service Contract Costs	Revenue from Sale / Auction
Qualification Costs	Upgrades / Software Costs	On-Demand (Pay-Per-Use) Costs	Write-Offs
	Supplies	Parts Costs	Taxes
	Operator Costs	In-House Engineer Labor Costs	
Enterprise Resource Planning (ERP) System			

Source: Martinko-Thermo fischer scientific, 2010

A wrong choice of equipment quickly becomes expensive in terms of its operation due to lost revenue, potential loss of customer-patients, lost productivity, idle worker costs, administrative labor costs to coordinate repair services, and communication with suppliers, the possible payment of overtime to make up for lost revenue and the possible purchase of new equipment (Martinko,2010).

1.3 Productivity Factor

The coefficient of productivity is critical for determining TCO, rational equipment management, and making strategic decisions regarding the selection of biomedical equipment. The aim is to improve the efficiency and performance of administrative, clinical and technical staff and the performance of laboratory equipment.

Table 3.

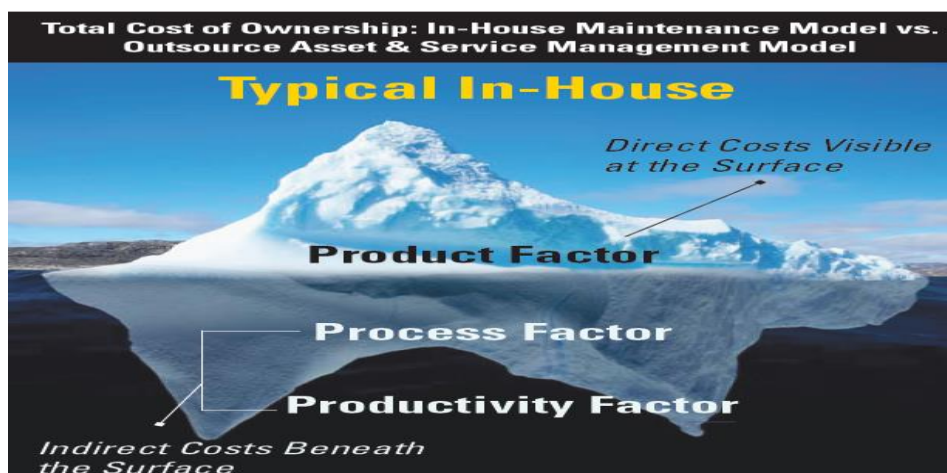
Productivity Factor (Costs related to benchmarking and measuring Key Performance Metrics)			
Acquisition	Operation	Maintenance	Disposition
Cost per Purchase Order	Clinical Operator Utilization	Uptime / Downtime (Elapsed Time To Repair ETTR)	# of Idle / Surplus Assets
Cost per Invoice	# of DRG's	Response Time	# of Assets Redeployed
# of Assets by Manufacturer	# Of Samples per Lab Technician	Mean Time To Repair	# of Assets Sold
# Of Assets by Equipment Modality	Asset Utilization	Same Day Fix Rate	
	Training Time	PM Completion Rate	
	Mean Time Between Failure	In-House Labor Utilization	
Enterprise Asset & Service Management System Functionality - Capture Data and Generate Reports			

Costs related to benchmarking and measuring key performance metrics

Source: Martinko-Thermo fischer scientific, 2010

The main indirect costs related to the factor of productivity include factors such as longevity of the product or service, energy consumption, installation costs, regular maintenance, repairs, upgrades, staff training, efficiency of the analytical platform, the TAT turnaround time and delivery of results, the menu of biomarkers available to the analyst, the reliability of the results produced by the analytical platform, the safety criteria, the ease of use, the capacity for technological modernization, and the personnel costs that must be evaluated for new installation (Hocket et.al., 2011 and Dabbs, 2017).

Figure 2.



Direct cost is only the tip of the iceberg

Source: Martinko-Thermo fischer scientific, 2010

The coefficient of productivity depends on effective benchmarking with past performance, productivity and comparison with other laboratories and organizations. The organization must identify critical success factors that must be put in place to achieve any specific performance metric goals.

The total cost of ownership of medical equipment often significantly exceeds the acquisition price, and therefore TCO appears to be the appropriate method for evaluating analytical platforms intended for in vitro laboratories. It has been pointed out that the purchase price can amount to only 20-25% of the total cost of ownership (Hospodková et.al., 2018).

2. literature review

2.1 Morphonios-Nierseen research study/outcomes

The studies (Morphonios et.al.,2014) and (Nierseen et.al.,2015) used a questionnaire survey on TCO as a total cost calculation process in the selection of an analytical platform. In completing the questionnaire (Table 4), 155 health care facilities and 21 hospitals took part (In total, 13 questions were asked in the survey). The acquisition cost in this study, includes the cost of the equipment, supply, the cost of auxiliary equipment, inspections, sales contracts, technical documentation and information from existing medical facilities were used as data sources. The operating costs include manufacturing costs, testing costs, training and technical support.

The energy cost was calculated based on device parameters (duration of active device operation, maximum electrical power of the device and the average price of electrical energy over the last 5 years). Personnel costs were calculated based on the standard number of

personnel and assays. Personal costs include mandatory employer contributions. The operating cost was calculated as the sum of all the above elements.

Maintenance costs were calculated based on technical service documentation for the last 5 years while the cost of medical examinations required according to equipment logs. No

Question	Response	Count	Percent
Do you assess the operating cost of the medical device before purchasing it?	yes	17	81,0 %
	no	4	19,0 %
Do you assess the operating cost of a given medical device in a retrospective review after a certain period of use?	yes	13	61,9 %
	no	8	38,1 %
Do you know what Total Cost of Ownership (TCO) method consists in?	yes	7	33,3 %
	no	14	66,7 %
Do you have an overview of the operating cost of individual devices in your healthcare facility?	yes	15	71,4 %
	no	6	28,6 %
Do you have any idea how much it will cost to dispose of individual devices at the end of their life cycle?	yes	10	47,6 %
	no	11	52,4 %

production costs identified, which usually include production losses, quality costs, environmental costs.

Table 4.

Survey questionnaire

Source: Hospodková, 2018, p.5

The first place in table 4 is occupied by the price of the device, second in line was the one related to the technical specifications, followed by: supplier service, the quality of the services provided and last but not least, the brand of the device.

Eight health care organizations suggested full service. The contract must be subject to serious negotiation to ensure a guarantee of technical service and the trouble-free operation of the equipment as well as the choice of the equipment supplier. The results of the study show that these items were in the third place in the order of importance for the TCO calculation of the equipment, which are usually included in the operating costs (Heilala,2006).

The conclusion of this study showed that the TCO calculation method of the medical equipment was unknown to most of the respondents and that the decisions were made based on the purchase price of the medical equipment. The operating costs over five years for the devices selected for the case study are comparable to their purchase price.

2.2 *Gontard & Cie Group research study/outcomes*

In the study by the consulting company Gontard&Cie Group, a total cost of ownership (TCO) analysis was carried out, comparing Abbott's Alinity ci automated analytical platform, with other analytical platforms from healthcare diagnostic companies Beckman, Coulter, Roche and Siemens.

Four independent laboratories were selected to participate in this study based on their size, the available assays on their menu, the installed analyzers and the annual assays consumption volumes.

Laboratories performed clinical chemistry and immunoassay testing for 30 analytes, 160 samples, developed a STAT emergency sample testing protocol, using a number of quality control and patient samples (134 tubes as routine samples/1,270 tests, 32 STAT tubes/180 tests). The urgent samples were processed to the analyzers at the same time in all laboratories with similar standardized protocols on five different analytical platforms from Abbott, Beckman Coulter, Roche and Siemens. Four main parameters of the TCO were examined:

- analyzer maintenance time
- sample processing time
- electricity consumption
- assays linearity interval

2.2.1 *Gontard & Cie Group study results*

Maintenance Time: The Alinity ci analyzer performed better than the other analytical platforms (Chart 1) in terms of both analyzer downtime and the number of staff hours required to perform maintenance. The Alinity ci series required 41%, 50%, 56% and 37% less annual maintenance time respectively compared to the other analytical platforms.

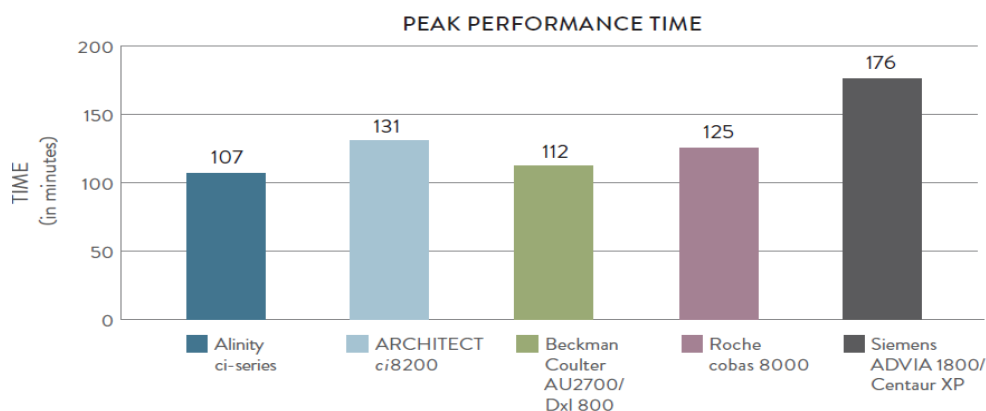


Chart 1.

Annual maintenance time on all analytical platforms (hours/time)

Source: P.C.G.Gontard, L.I. Stankevich, B.G. Gorodetsky, 2018

Processing time: The Alinity ci series processed 172 tubes in 107 minutes, which was 4.5%, 14%, 39%, and 18% faster than Beckman Coulter, Roche, Siemens, and Abbott Architect analyzers, respectively (Chart 2) .

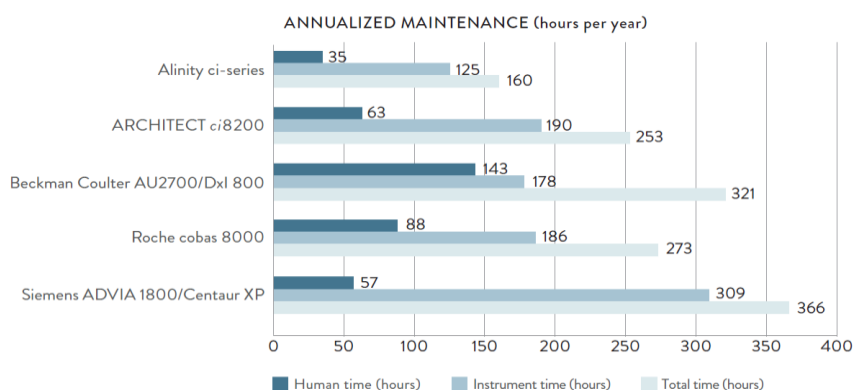


Chart 2.

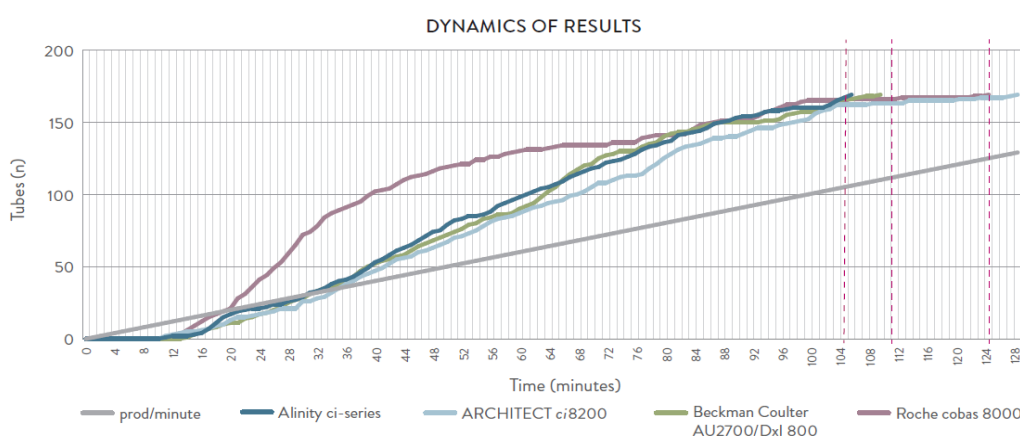
Processing speed (throughput) of analytical units (Peak period)

Source: P.C.G. Gontard, L.I. Stankevich, B.G. Gorodetsky, 2018

Processing dynamics: The Alinity ci series achieved the fastest peak performance time (Peak Performance - dotted lines) while the Roche Cobas 8000 platform had the fastest processing speed, up to the first 130 samples, which then reached a "saturation" effect system (Chart 3).

Chart 3.

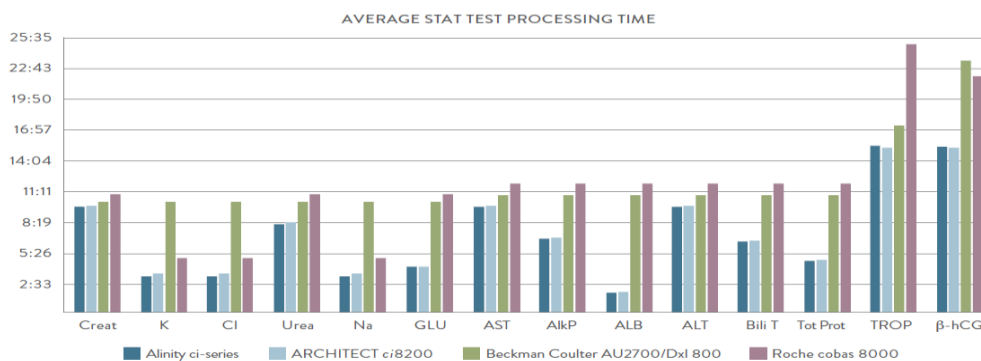
Dynamic sample processing on all analytical platforms



Source: P.C.G. Gontard, L.I. Stankevich, B.G. Gorodetsky, 2018

STAT processing: Assays were used with emergency profile tests such as Troponin-T and β -hCG. For all STAT assays, Alinity ci-series and ARCHITECT ci 8200 platforms had lower processing times compared to Beckman Coulter Platform AU2700 / DxI800 and Roche cobas 8000, while similar times were found for STAT processing of Creatinine, AST and ALT on the four analytical platforms (Chart 4).

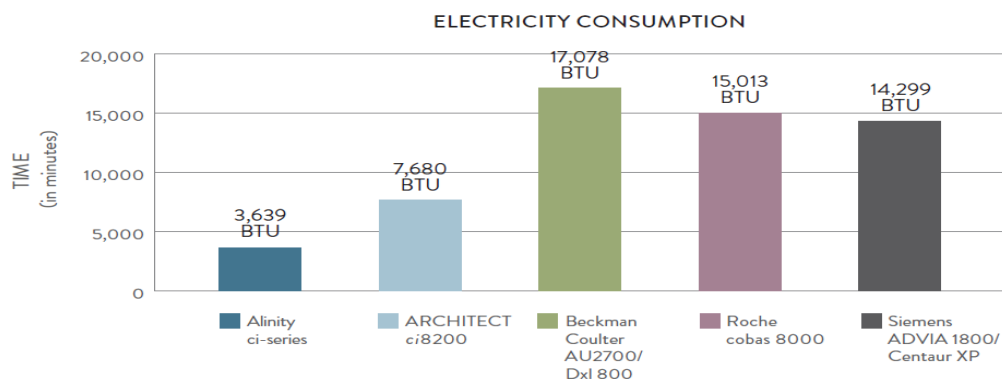
Chart 4. Average STAT time per test comparison for each platform



Source: P.C.G. Gontard, L.I. Stankevich, B.G. Gorodetsky, 2018

Power consumption: The Abbott Alinity ci-series platform consumed 75%, 76%, 79%, and 53% less power, respectively, than the Roche, Beckman Coulter, Siemens, and Abbott ARCHITECT platforms (chart 5).

Chart 5.



Electricity consumption by each analytical platform

Source: P.C.G. Gontard, L.I. Stankevich, B.G. Gorodetsky, 2018

Assay Linearity: In addition, the linearity range on each analytical platform was evaluated as a key factor in operational performance (Charts 6-9). The reduced linear scale of the tests creates additional replicates and dilutions that have a negative impact on the expected time to deliver a result to patients while doubling the cost of analyzing samples for the laboratory.

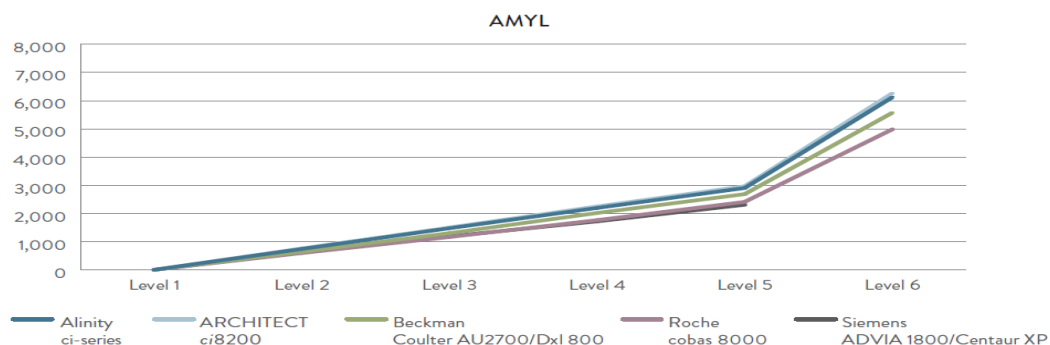
Table 5. Linearity of control sample measurements

Analyte	Platform	C1	C2	C3	C4	C5	C6
ALT	Abbott Alinity ci-series	9.2	220	433	644	852	3,271
	Abbott ARCHITECT ci8200	9.5	221	430	644	854	3,561
	Beckman Coulter AU2700/Dxl 800	8.5	205	404	637	859	3,677
	Roche cobas 8000	7.0	198	390	578	788	3,345
	Siemens ADVIA 1800/Centaur XP	9.5	223	434	639	849	3,270
AST	Abbott Alinity ci-series	6.4	213	416	618	818	3,634
	Abbott ARCHITECT ci8200	6.8	209	411	613	813	3,613
	Beckman Coulter AU2700/Dxl 800	7.0	216	422	621	844	4,017
	Roche cobas 8000	4.5	210	411	606	814	3,643
	Siemens ADVIA 1800/Centaur XP	9.0	217	425	628	838	3,551
AlkP	Abbott Alinity ci-series	5.9	518	1,014	1,506	1,978	3,972
	Abbott ARCHITECT ci8200	5.8	542	1,060	1,573	2,066	4,188
	Beckman Coulter AU2700/Dxl 800	<5	582	1,141	1,781	2,375	4,808
	Roche cobas 8000	4.0	410	792	1,161	1,564	3,091
	Siemens ADVIA 1800/Centaur XP	3.0	429	803	1,167	1,555	3,130
Amyl	Abbott Alinity ci-series	6.3	746	1,478	2,197	2,904	6,119
	Abbott ARCHITECT ci8200	6.5	762	1,505	2,251	2,967	6,258
	Beckman Coulter AU2700/Dxl 800	6.0	647	1,305	2,019	2,688	5,571
	Roche cobas 8000	5.0	600	1,167	1,767	2,413	4,983
	Siemens ADVIA 1800/Centaur XP	6.0	637	1,193	1,722	2,310	N.R.

C = concentration of the control samples in U/L, with increasing concentration of analytes from C1 through C6
ALT = alanine transaminase; AST = aspartate transaminase; AlkP = alkaline phosphatase; Amyl = amylase; N.R. = no result

Source: P.C.G. Gontard, L.I. Stankevich, B.G. Gorodetsky, 2018

Chart 6. Measurement of the linearity of the quality control samples at various concentrations of ALT

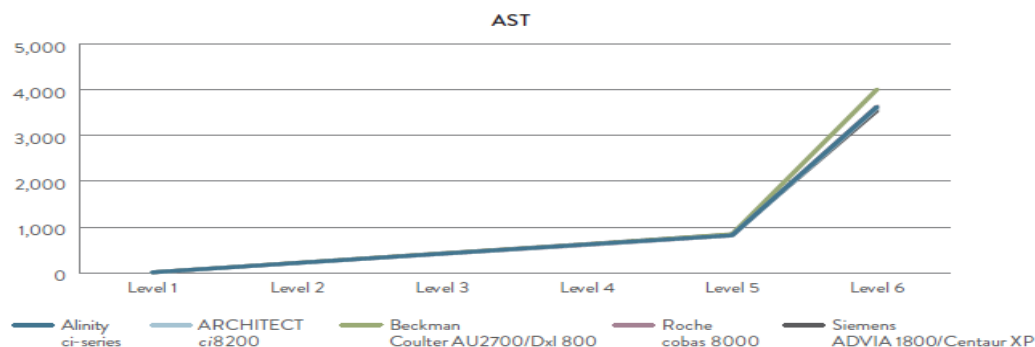


test

Source: P.C.G.Gontard¹, L.I. Stankevich¹, B.G. Gorodetsky, 2018

Chart 7.

Measurement of the linearity of the quality control samples at various concentrations of the AMYL



Source: P.C.G.Gontard¹, L.I. Stankevich¹, B.G. Gorodetsky, 2018

Chart 8.

Measurement of the linearity of the quality control samples at various concentrations of the AST

Source: P.C.G.Gontard¹, L.I. Stankevich¹, B.G. Gorodetsky, 2018

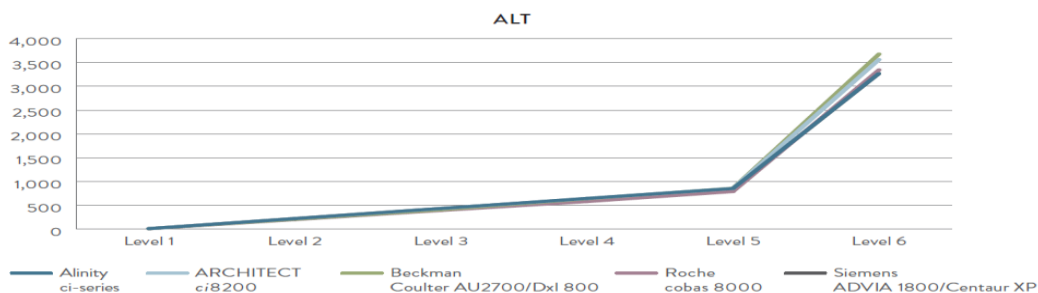
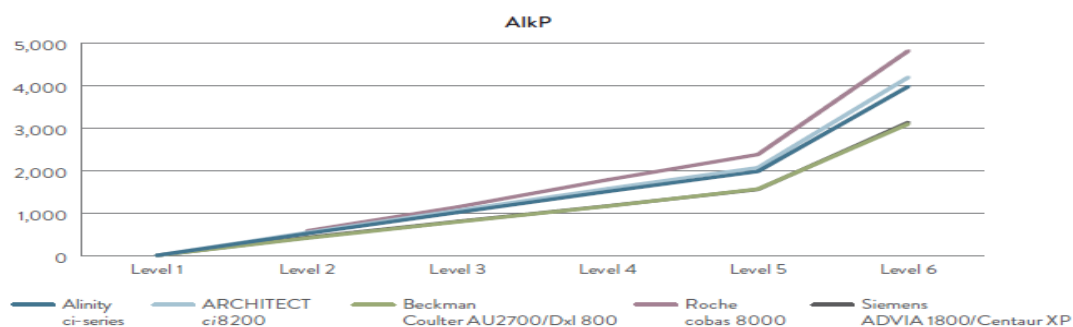


Chart 9. Measurement of the linearity of the quality control samples at various concentrations of the ALKP

Source: P.C.G.Gontard¹, L.I. Stankevich¹, B.G. Gorodetsky, 2018



Overall, the results of the Gontard & Cie Group study regarding the operational performance indicators of the analysts are presented in table 6 below, while tables 7-10 of the study, is illustrated a holistic presentation of the factors affecting the final cost in the biopathology laboratory.

Alinity ci Platform	Architect c8200	Beckman Coulter AU2700/Dx800	Roche cobas 8000	Siemens ADVIA 1800/ Centaur XP
Alinity ci χρόνος συντήρησης	-37%	-50%	-41%	-56%
Alinity ci χρόνος επεξεργασίας	-18%	-4.5%	-14%	-39%
Alinity ci ηλεκτρική κατανάλωση	-53%	-79%	-76%	-75%

Table 6.

Summary of superiority of TCO factors for the Alinity ci analytics platform (The negative sign indicates superiority)

Source: P.C.G. Gontard, L.I. Stankevich, B.G. Gorodetsky, 2018

In the same study by Gontard & CIE Group, a comparison of the traditional calculation of the costs of the in vitro laboratory with the modern approach of TCO was attempted (Table 7).

Comparison	Traditional cost	Total cost (TCO)
Supply costs of consumables and reagents	✓	✓
Calibrators and quality control samples	✓	✓
Equipment cost analysis	✓	✓
Operating Costs	✓	✓
Maintenance equipment time & employment of staff for the purpose		✓
Cash flows	✓	✓
Staff training to improve operational performance		✓
Calibration, QC, Reagent loading		✓

Table 7.

Laboratory functions affecting the final cost

Source: P.C.G. Gontard¹, L.I. Stankevich¹, B.G. Gorodetsky, 2018

Comparison	Traditional Cost	Total Cost (TCO)
Assay linearity limits on analytical platforms will play an important role in avoiding repeat-dilutions for patient samples that exceed assay linearity scale limits		✓
Ease use of the equipment		✓
Real-time data analysis and elevates the laboratory as a decision support center		✓
KPI improvements		✓
Job satisfaction		✓

Table 8.

Laboratory functions affecting the final cost (continued)

Source: P.C.G. Gontard¹, L.I. Stankevich¹, B.G. Gorodetsky, 201)

Comparison	Traditional Cost	Total Cost (TCO)
Necessary CDC standardization protocols that optimize workflow and ensure indirect revenue for the laboratory		✓
Space saving benefits. The use of the space translates into an increased volume of examinations and utilization for others. Laboratory activities, which increase the incomes		✓

Optimal inventory management, e.g. priority in the use of reagents and consumables with a close expiration date		✓
---	--	---

Table 9.

Laboratory functions affecting the final cost (continued)

Source: P.C.G. Gontard¹, L.I. Stankevich¹, B.G. Gorodetsky, 2018

Comparison	Traditional Cost	Total Cost (TCO)
Turnaround time (TAT-Peak Performance type) leading to resource utilization and laboratory efficiency and ultimately improving the service provided by clinicians		✓
Time (Startup time) required to start processing the analyzer		✓
Cost of consumables, waste management. Waste management is estimated to account for 30% of total healthcare costs		✓

Quality six sigma results through the selection of appropriate diagnostic instruments & assays specifications		✓
---	--	---

Table 10.

Laboratory functions affecting the final cost (continued)

Source: P.C.G. Gontard¹, L.I. Stankevich¹, B.G. Gorodetsky, 2018

2.3 Francis et. al. study/outcomes

A parallel reference to the study (Francis et. al., 2009; Li, L. et. al., 2015), conducted in 4 Australian hospitals over a period of 2 months (August and September) and 4 years (2008-2011) aimed to investigate the relationship between laboratory tests (including test, test volume), time to completion (TAT) and length of staying (LOS) in the emergency department (ED). The study was presented at the Australian Conference of Applied Statistics, Queenstown, New Zealand, December 2012 and sponsored by the Australian Government Department of Health entitled: Quality use of the Pathology program. In this particular study, the ED (Emergency Department) strategy was to reduce patient length of stay and hospital occupancy by encouraging physicians to use assays selection boards to order tests based on patient symptoms.

Conclusions: As the number of tests requested increased, so did patients' ED LOS (Length of staying).

-For every five additional tests ordered, average ED LOS increased by 10 minutes (2.9%)

-A 30-minute increase in TAT time was associated, on average, with a 5.1% (17 minute) increase in ED LOS.

Consequently, laboratory TAT, patient numbers, and test volume affect ED LOS. Targeted increases in ED resources and staffing may also help reduce ED LOS. Patient crowding in EDs causes saturation and has been shown to lead to medical errors that lead to increased mortality and decreased health care organization reputation and potential financial

impact. The results of this study are crucial for diagnostic work-up and patient management decisions, and therefore potentially have a significant impact on patient flow in the ED.

Complementary research: The issue of the association of TAT with average patient ED LOS is also discussed in the simulation study conducted by Storrow et. al. (2008). This particular study used a sophisticated simulation model for ED involving 55,000 patients.

Data were generated using an analytical system modeling and simulation approach over 90 separate days from December 2, 2007, to February 29, 2008. The model was a continuous simulation of ED flow, based on real-time patient data. A comparison of laboratory results was attempted at 120, 100, 80, 60, 40, 20 and 10 minutes.

1st Outcome: Reducing TAT could improve performance in emergency departments and subsequently reduce patient waits in specific hospital departments. An average 30-minute increase in TAT time resulted in a 17-minute increase in patient attendance ED LOS (Chart 10-11).

2nd Outcome: As laboratory turnaround time decreased from 120 to 10 minutes, the total number of diversion days (maximum 57 at 120 minutes, minimum 29 at 10 minutes), average diversion hours per day (10.8 hours vs. 6.0 hours), percentage of days with diversion (63% vs. 32%), and mean ED LOS (2.77 hours vs. 2.17 hours)

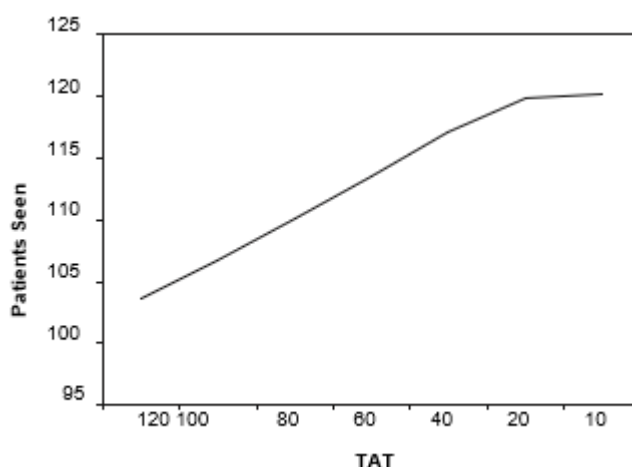
gradually decreased, while mean daily throughput (104 patients vs. 120 patients) increased (Table 11). Calculations were made with at least 85% accuracy. This simulation model suggests an exciting improvement in the efficiency of EDs by reducing the time to complete laboratory results.

The Effect of Decreasing Lab Turnaround Time on ED Efficiency Measures					
Simulated TAT (Minutes)	Total Diversion Days	Average Diversion (Hours)	Diversion Days (%)	Average Patients Seen/ Day	ED LOS (Hours)
120	57	10.8	63	103.51	2.77
100	56	11.0	62	106.7	2.6
80	49	9.9	54	110.02	2.43
60	42	8.5	47	113.52	2.27
40	33	6.8	37	116.98	2.17
20	30	6.2	33	119.88	2.17
10	29	6.0	32	120.08	2.17

Table 11. The effect of reducing TAT from 120 to 10 minutes on ED performance

Source: Storrow et. al., 2008

Chart 10.



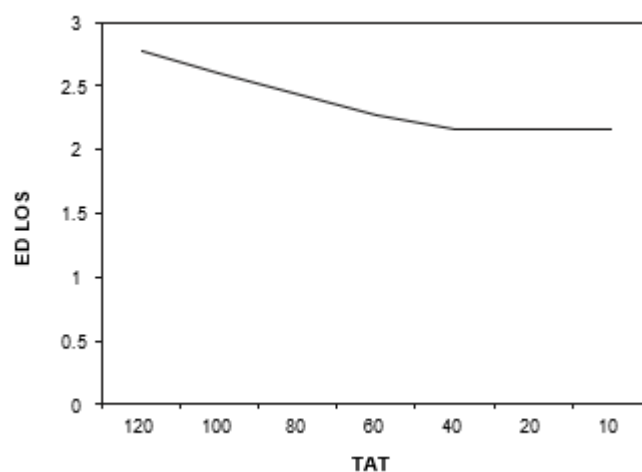
The effect of TAT processing time on percentage of patients

Source: Storrow et. al., 2008

The National Academy of Clinical Biochemistry further recommends that the turnaround time for cardiac stat testing should be 1 hour or less. Institutions that cannot provide this consistently should implement point-of-care devices.

Unfortunately, there is a lack of well-designed assays that have addressed clinical and patient-oriented outcomes. This disadvantage, namely the generally higher cost of point-of-service testing, administrative implementation hurdles, and the difficulty in performing the required size testing support the initial use of a robust simulation model (Storrow et. al., 2008).

Chart 11. *The effect of TAT processing time on ED LOS rate*

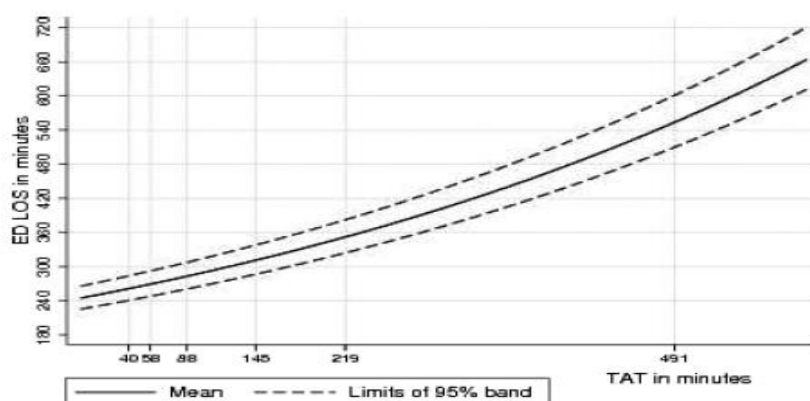


Source: Storrow et. al., 2008

According to the article Li, L. et. al. (2015) several strategies have taken place, such as improving pre-analytical procedures in specimen management and automation resulting in improved test turnaround time and a significant reduction in LOS in the ED (Chart 12). TAT for any hospital service is related to hospital time and resources.

Chart 12.

Mean LOS (x-axis values are the 25th, 50th, 75th, 90th, 95th, and 99th percentiles of TAT) for patients aged 31 to 50 years in EDs between 1-7 AM.



Source: Li, L. et. al., 2015

3. RESEARCH OBJECTIVE, METHODOLOGY AND DATA ANALYSIS

3.1 Research Strategy

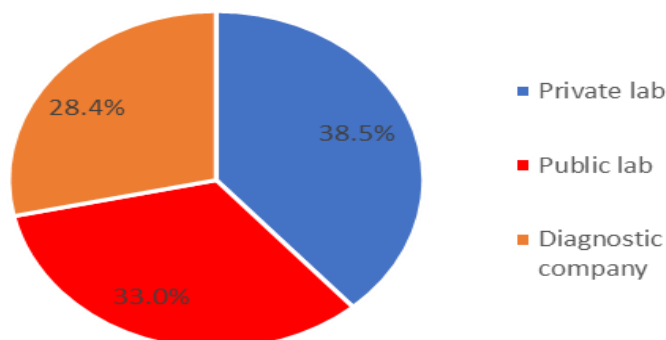
A targeted survey was conducted in order to find out the beliefs of healthcare professionals about the acceptance or not of applying the philosophy of total cost of ownership TCO in the selection of in vitro analytical system. Executives and staff from public and private in vitro Greek laboratories as well as health professionals from diagnostic companies participated in the specific research. The study was carried out using a questionnaire, which included the demographic characteristics of the population that took part in the research as well as questions that make up the standard model of the total cost of ownership.

3.2 Sample Characteristics and Applied approach

109 responses were given, while the survey participants had the following characteristics: 38.5% were employed in the private sector, 33% in public in vitro laboratories, while 28.4% were experienced executives of diagnostic companies with particular activity in the field of in vitro laboratories (Chart 13).

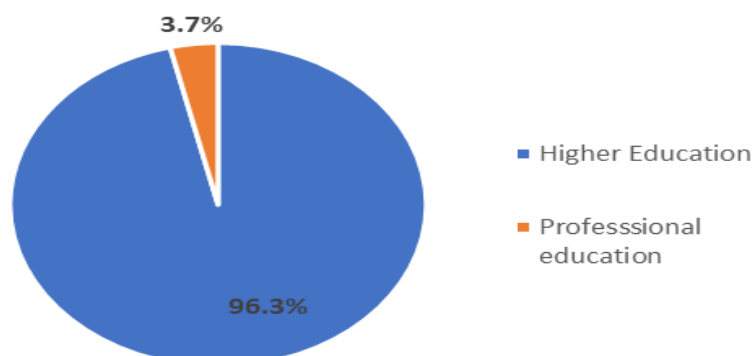
Chart 13.

Sector of employment of the respondents



Regarding their level of education, the vast majority of the public at 96.3% have a higher level of education (Chart 14) with 70.6% being between 41-60 years old, 21.1% between 26-40 years old, 6.4% over 61 and just 1.8% under 25. A percentage of 72.5% was a member of an organization with more than 100 employees, 14.7% were employed in an organization of 30-100 employees, 10.1% in smaller organizations of 10-30 employees, while only 1, 8% corresponds to a laboratory with a staff of less than 10 people.

Chart 14.



Level of education of the respondents

The majority of respondents held important positions, which allows them to make strategic decisions on the selection of biomedical equipment for their in vitro laboratories or, in the case of commercial diagnostic companies, to make sells of biomedical equipment using the Total cost of ownership criteria.

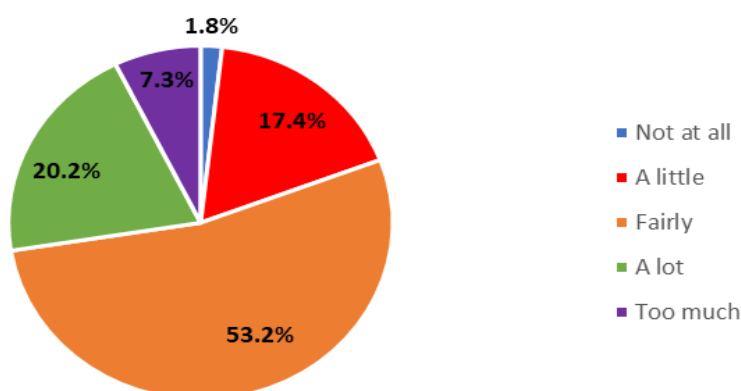
The aim of the research is to investigate if there is a potential of the selection of an in vitro laboratory equipment and specifically a biochemical/immunological analytical platform, using the criteria of the total cost of ownership seriously considered not only the direct financial costs arising from the pricing of the reagents, the consumables, and the equipment but also the indirect operating costs of the analytical platform throughout its lifetime.

4. Findings

The basic question, which concerns exclusively the visible economic cost concerning the pricing of reagents (Chart 15), consumables, purchase or loan of the equipment as the main factor, which will determine the choice of equipment of the in vitro laboratory is positively addressed - the 53, 2% state '*fairly*', 20.2% '*A lot*' and 7.3% '*Too much*' - as the percentage appears particularly high and indicates a passive attitude towards the adoption of TCO and a short-term perspective direction of the equipment and of the laboratory budget. Of course, it should be emphasized that this question only includes financial cost as a selection factor.

Chart 15.

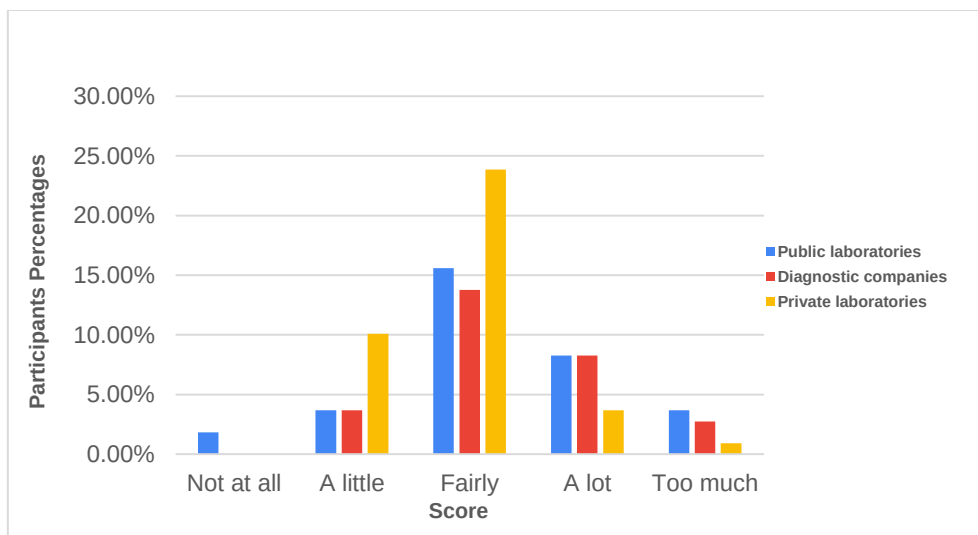
The financial cost as an exclusive factor for selecting equipment



It would be of particular value to illustrate the difference in philosophy that dominates the public laboratory, private laboratory and also among professionals of diagnostic companies in the sector. In the diagram below, the vertical axis shows the number of participants in absolute percentages, while the horizontal axis shows their score regarding pricing as the main decision factor.

Chart 16.

Financial cost as a main factor in equipment selection

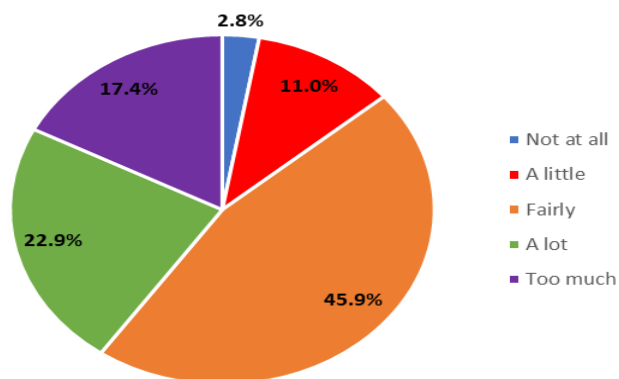


In the private sector, 61.90% answered 'Fairly' and seems to take pricing seriously as they seek short-term immediate profits that will support the costs of the lab and potentially provide additional financial benefits to their management. Despite this, only 11.9% rated it from 'A lot' to 'Too much'. The corresponding percentages in the public laboratory are: 47.22% 'fairly' and 36.11% from 'A lot' to 'Too much', while in the diagnostic companies they are: 48.39% 'fairly' and 38.71% from 'A lot' to 'Too much'.

The encouraging fact for the TCO philosophy, is that when the indirect costs resulting from the choice of an analytical examination platform throughout its life are clearly stated (Chart 17), the majority of respondents seem to answer positively, and indeed with an overwhelming percentage of the order of 86.2% on the grading scale from 'fairly' to 'Too much'.

Chart 17.

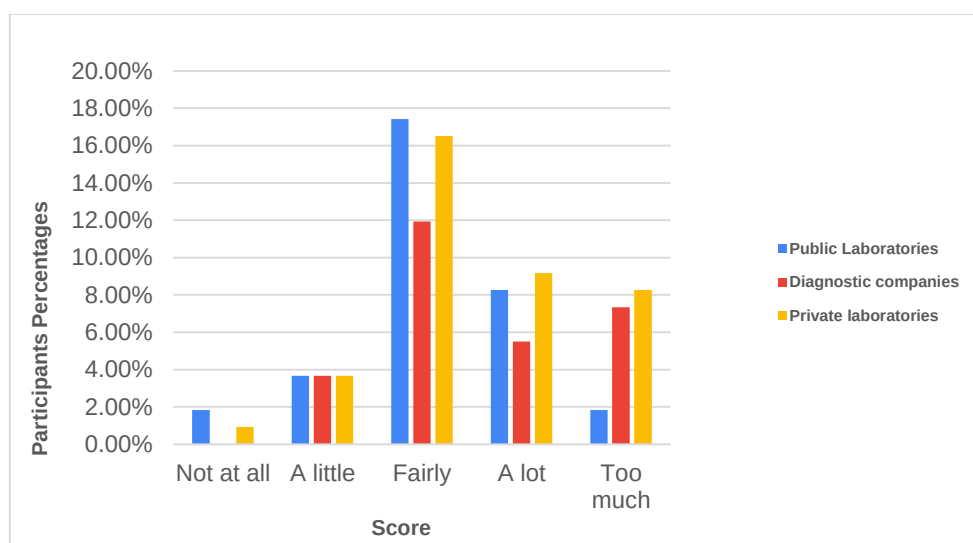
The indirect costs in the choice of analytical platform



As shown in Chart 18 below, particular importance is attached to the indirect costs of operating the analytical platform throughout its lifetime in both the public and private sectors with corporate healthcare professionals to follow. 83.34% of the public sector, 88.11% of the private sector and 87.11% of diagnostic companies are classified in the category from 'fairly' to 'Too much'. The percentages with a rating from 'A lot' to 'Too much' are of particular importance. The corresponding percentages are 30.56% for the public sector, 45.24% for the private sector and 45.16% for companies in the health diagnostic sector.

Chart 18.

The importance of indirect costs



In addition, questions were asked that refer to the quality characteristics of the tests and the reliability of patient results, and whether these are related to the indirect costs generated by the operation of the analytical platform (Charts 19-22). The public participating in the survey considers that the quality of the tests as well as the reliability of the clinical results to be parameters for determining the total cost of the laboratory burden. The quality specifications of the tests remove the risk of increasing tests, their repetitions and dilutions due either to their limited linearity or to the sensitivity of the analytical instrument.

Chart 19.

The quality of assays as one of the TCO selection criteria

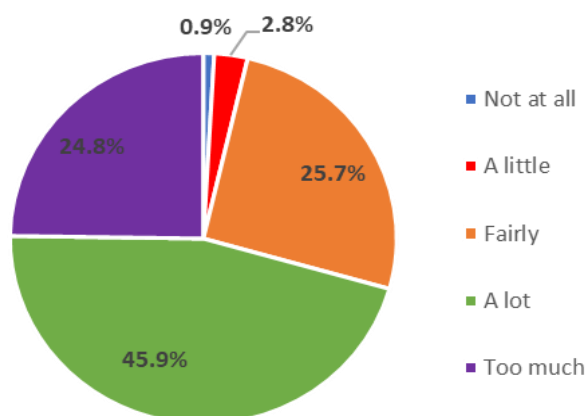


Chart 20.

The linearity of assays as one of the TCO selection criteria

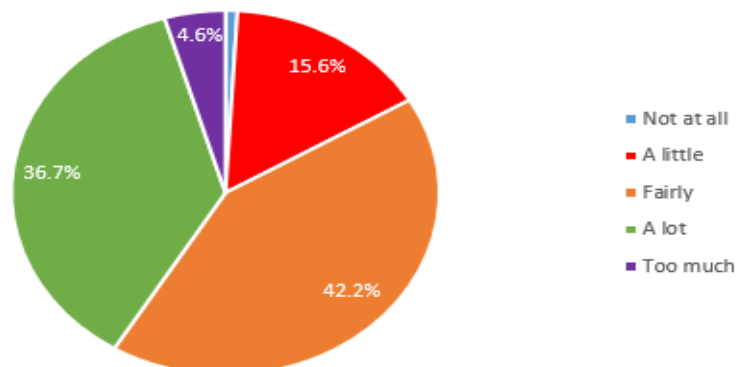


Chart 21.

The reliability of patient results

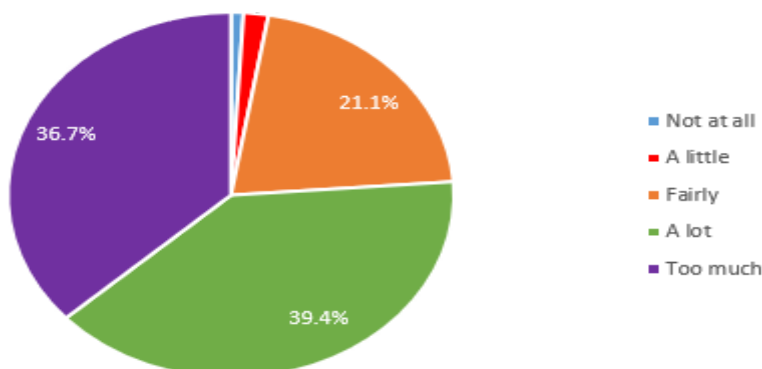
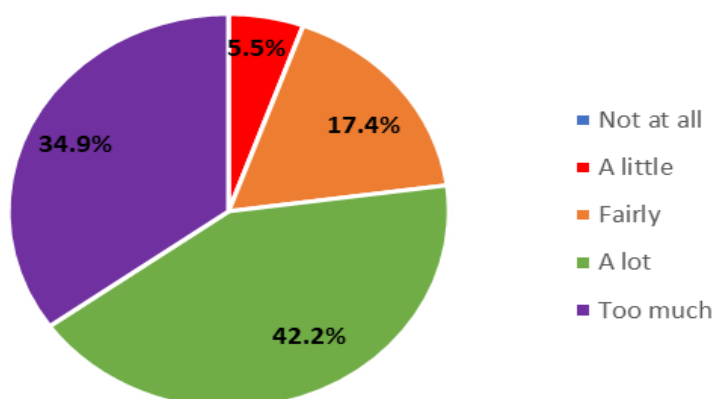


Chart 22.

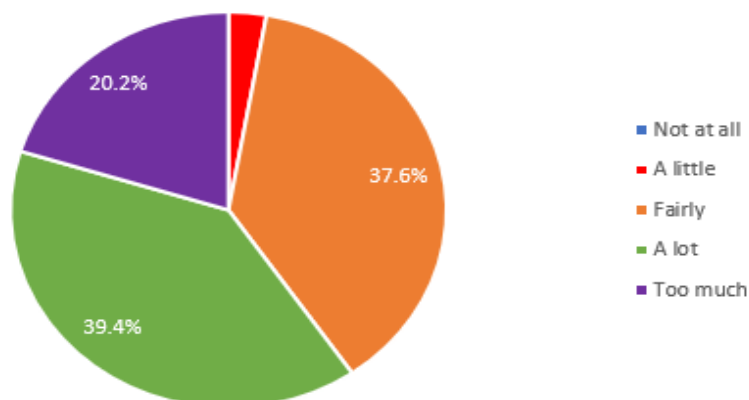
The effect of assays quality on the budget of the health care organization



The clear question of whether to choose new equipment for the laboratory based on the TCO could optimize the laboratory budget, receives a clear response from respondents in favor of applying TCO and indicates a clear attitude towards effective analyzer selection. From the 97.2% who move on the grading scale from 'fairly' to 'Too much', a particularly significant percentage of 59.6% categorically believes that in the long term the application of TCO in the selection of laboratory analytical equipment contributes decisively to the reduction of expenses of the in vitro laboratory and broadly in the budget of the health organization.

Chart 23.

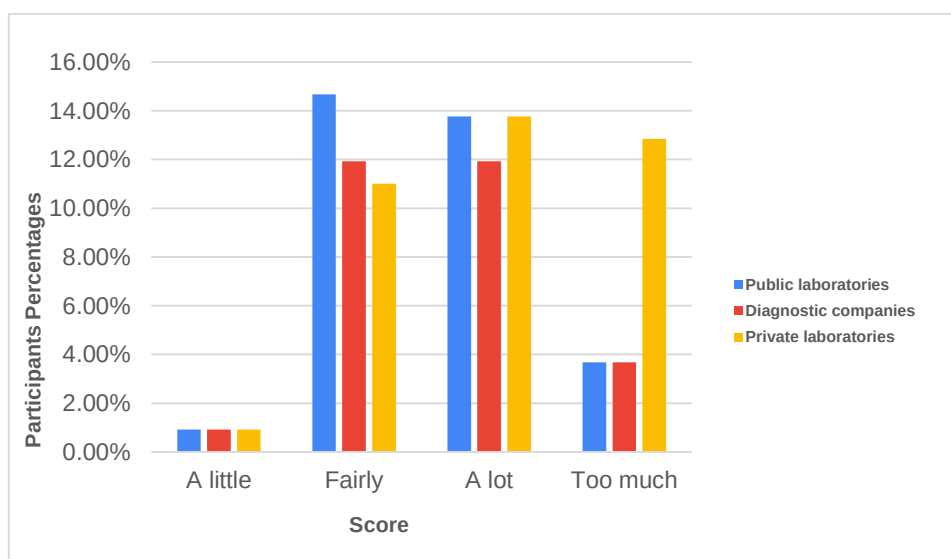
The TCO in relation to the budget of the in vitro laboratory



They do not focus on the cost of procurement of reagents, consumables, equipment but carry out a full investigation of the capabilities of the equipment while looking in depth at factors that determine the total cost of ownership TCO, which could provide qualitative as well as quantitative added value to the laboratory. In chart 24 below, is attempted a comparison between the views prevailing in the different health sectors on the effect of the total cost of ownership.

Chart 24.

Impact on the laboratory budget



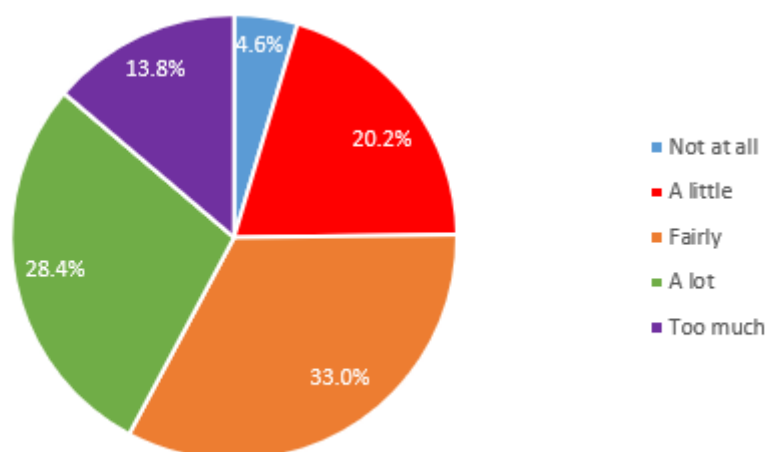
97.22% of the public sector, 97.61% of the private sector and 96.78% of diagnostic companies are classified in the category from 'fairly' to 'Too much'. The percentages with a

score from 'A lot' to 'Too much' are 52.78% for the public sector, 69.04% for the private sector and 54.84% for companies in the health diagnostic sector.

In the corresponding question (diagram 25), as indicated by the percentages of 75.2% with a rating from 'fairly' to 'Too much', the effect of the total cost of ownership TCO on the stay of patients in outpatient clinics or inpatient clinics is considered critical. The research method of Francis et. al. (2009), by Li, L et al. (2015) and Storow et. al.(2008), in which the significant effect of results processing time on reducing waiting, emergency department decongestion and patient hospitalization was determined.

Chart 25.

Effect of TCO on patient stays in emergency department and inpatient clinics

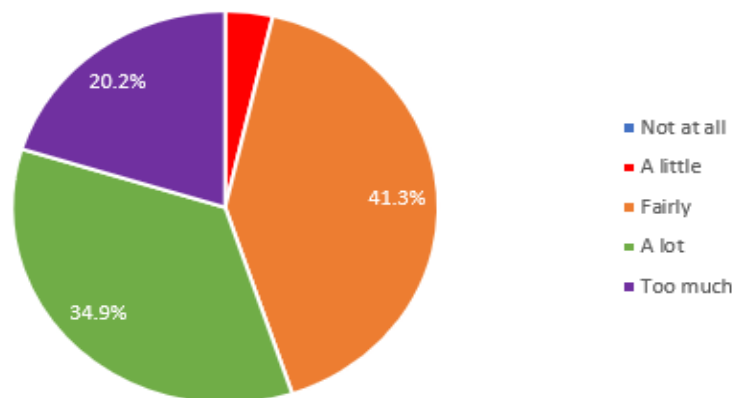


Despite this, a percentage of 42.2% considers the effect of TCO on the stay of patients in outpatient clinics or clinics to be critical, while a significant percentage of 24.8% does not believe that the total cost theory could have an important role in decongesting nursing institutions.

In the question of whether the total cost of ownership could contribute to the budget of the wider health organization, an overwhelming percentage of 96.4% with a rating from 'fairly' to 'Too much', respond positively (Chart 26).

Chart 26.

Contribution of TCO to the budget of the wider health organization



The previous question is specialized, and we are looking for the approximate percentage of participation of the TCO in the budget of the health organization. Specifically, from the analysis of the relevant responses depending on the health agencies participating in the research, the following Charts 27 and 28 emerge:

Chart 27.

Percentage of TCO participation in the total budget of the health organization

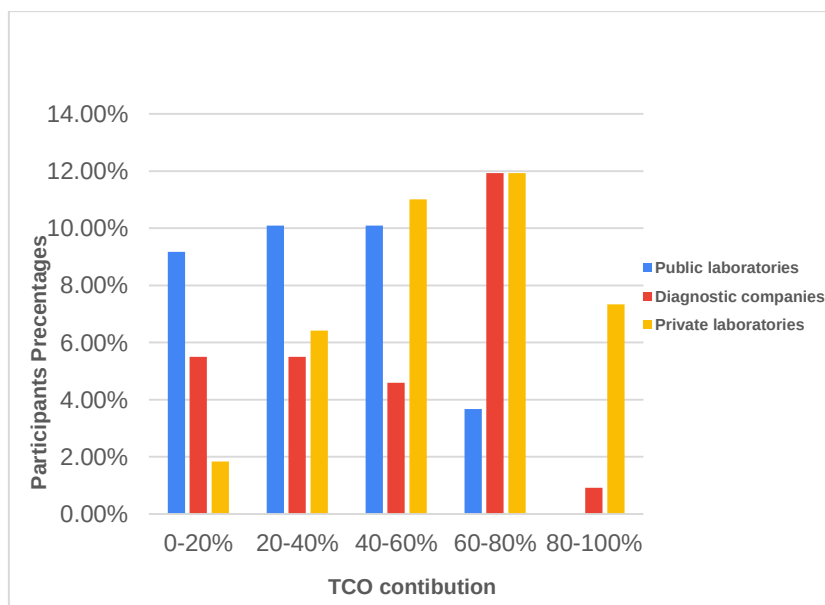
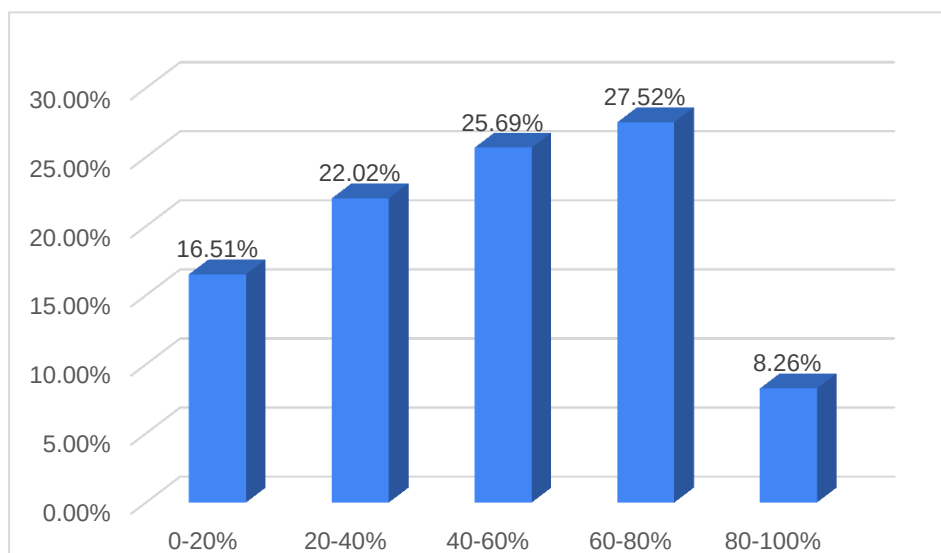


Chart 28.

Contribution rate of TCO to the overall budget of the healthcare organization



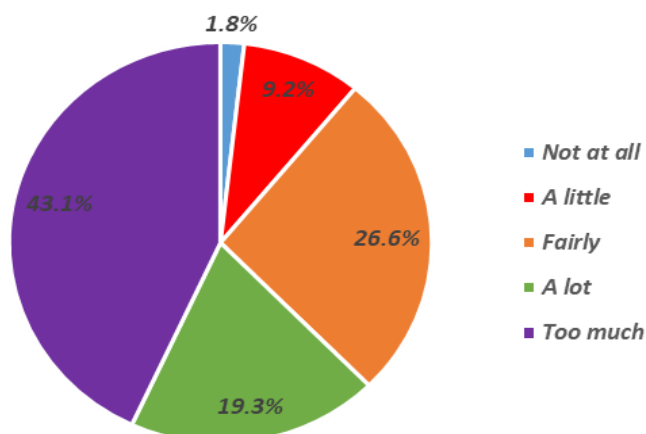
The contribution rate of TCO to the health organization's budget prevails by 60-80% with the designation 'A lot' and also the designation 'fairly' with a percentage of 40-60%, while there is also a public that declares 20-40% to the effect of TCO in the budget of the health organization's budget, which is in line with the 24.8% who in a previous question considered the impact of the total cost of in vitro laboratory equipment on the effective management of patients in outpatient clinics and inpatient clinics as not critical. In the public laboratory, 30.56% consider that TCO contributes 40-60% to the health organization's budget, while only 11.11% contribute 60-80%. In the private sector, 30.95% answer 60-80% while there is also a calculable percentage of 19.05% that appears true to the TCO philosophy as it chooses the effect of 80-100% on the overall budget of the health organization. Health professionals, who work in diagnostic companies in the sector rated 60-80% in 41.94% and 80-100% in 3.23%.

The total cost of ownership as a decision mindset for the selection of analytical equipment could positively affect the laboratory budget and the overall budget of the health organization as well as qualitatively upgrade laboratory practices.

Regarding the deactivation of the analyzers (Downtime) either due to a mechanical problem or due to preventive maintenance, we find the universal acceptance of the public, which clearly considers that the deactivation time of the analyzers is an obstacle to the proper operation and efficiency of the laboratory (Chart 29). The operational reliability of the analyzer and the effective intervention and response of the clinical engineering team are essential elements of the TCO and are decisive for the normal operation of the laboratory.

Chart 29.

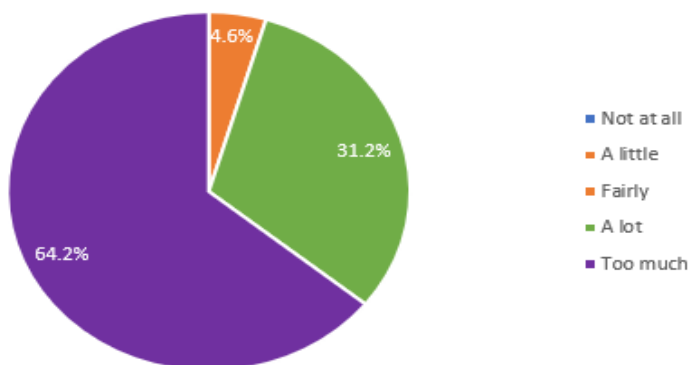
The efficiency of the laboratory depending on the deactivation time of the analyzers



The opinion that the training of the operators is a crucial factor in the proper operation and promotion of the laboratory work is also received by very large percentages. Training should be provided in an organized manner to new staff and be a dynamic and methodical process for all laboratory workers as equipment changes, software upgrades are made, resulting in new capabilities being created (Chart 30).

Chart 30.

The role of operator training in the efficient operation of the laboratory

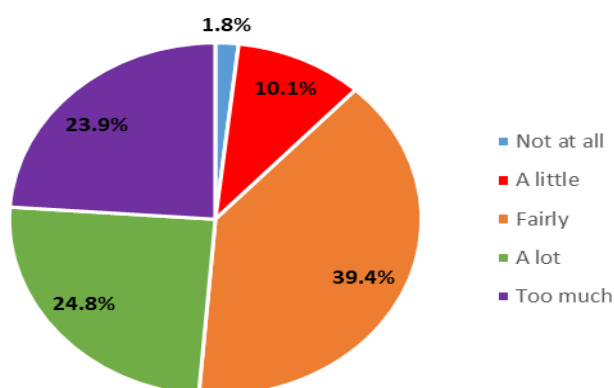


In the research study, there are two questions about the waste generation of the analyzers (Charts 31-32). It is investigated whether the production of waste come from

the analytical platform - an element mentioned in the specifications of the analytical platform - creates costs for the laboratory but also affects the environmental footprint and the reputation of the laboratory. It is a fact that the procedures required for the collection and subsequent inactivation and deactivation of waste is a costly process. In addition, in an era of environmental awareness and the promotion of sustainable business development, the effort to reduce the environmental footprint is viewed very positively by the community.

Chart 31.

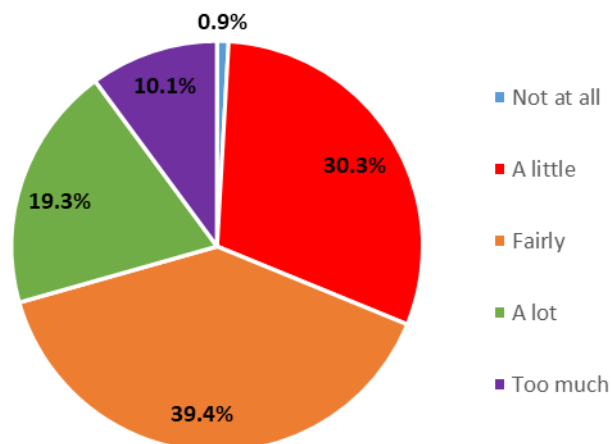
Environmental footprint and reputation of the laboratory



Despite suggesting an agreement that the amount of waste generated by the analyst could influence the decision to choose an analytical platform looking for the details we can distinguish a respectable percentage of 30.3% that does not take into account in the selection decisions, the waste factor generated by the analytical platform.

Chart 32.

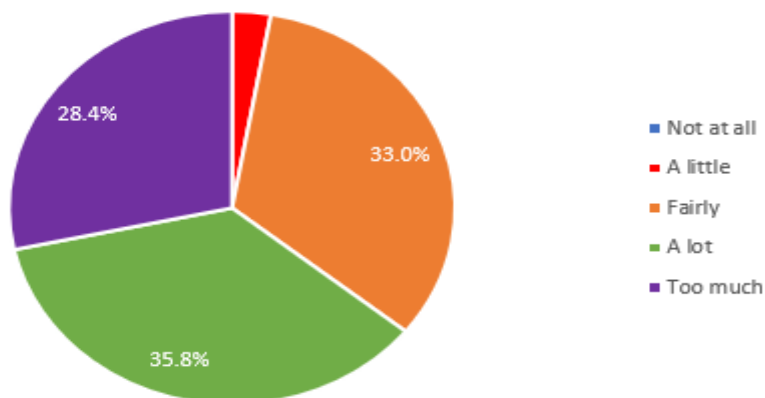
The waste generation from the analytical platform as a selection criterion



As illustrated in Chart 33 below, agreement is found on the general question of whether total cost of ownership is an evidence-based approach to calculating total cost.

Chart 33.

According to survey participants, TCO is a documented approach to calculating total cost

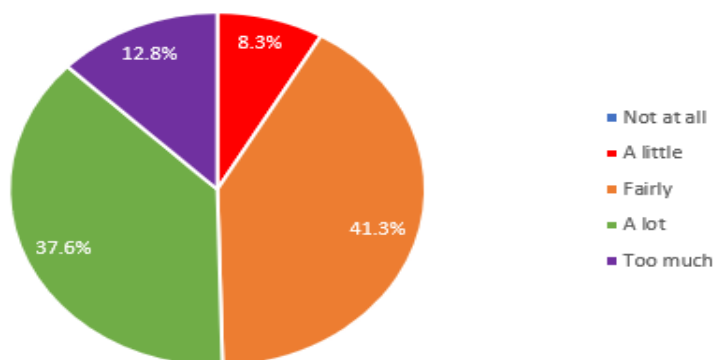


The vast majority of respondents (91.7%) indicate as significant the difference resulting from the analysis of the direct economic costs related to the pricing from the corresponding analysis of the total cost of ownership TCO, which also contains the indirect costs (Chart 34). The total cost of ownership TCO is accepted as an evidence-

based approach to calculating total costs and as an indicator of the development of the laboratory's reputation in the hospital and in the wider healthcare field.

Chart 34.

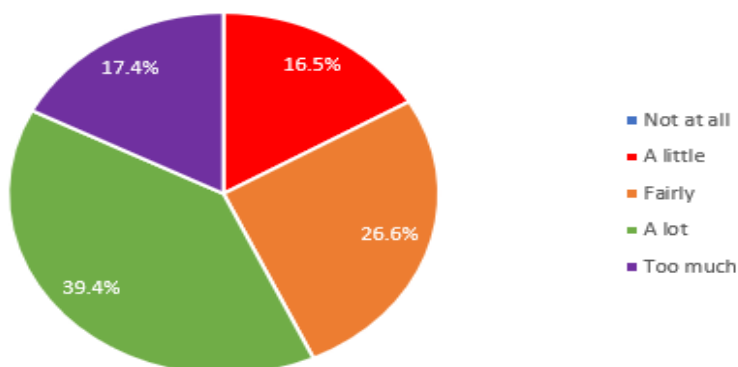
The difference between the economic cost analysis and the analysis containing the indirect costs of the biomedical equipment was judged



83.4% from 'fairly' to 'Too much' in the following poll state that the total cost of ownership is an indicator of the development of the reputation of the laboratory in the hospital and more broadly in the field of health (Chart 35).

Chart 35.

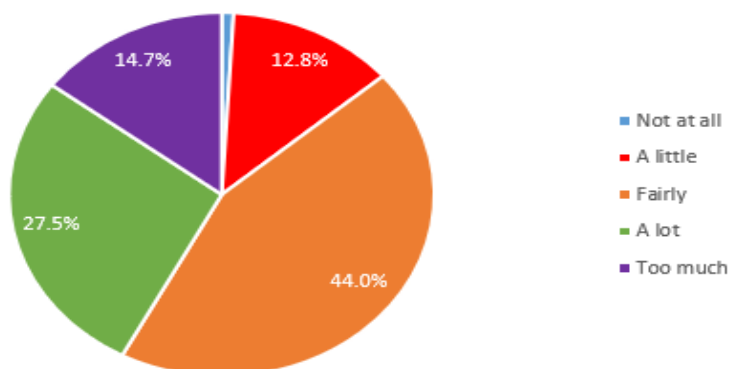
TCO as an indicator of the development of the reputation of the laboratory



Saving space receives a positive response of 86.2% on a scale from 'fairly' to 'Too much' (Chart 36).

Chart 36.

Saving space improves the KPI of the laboratory

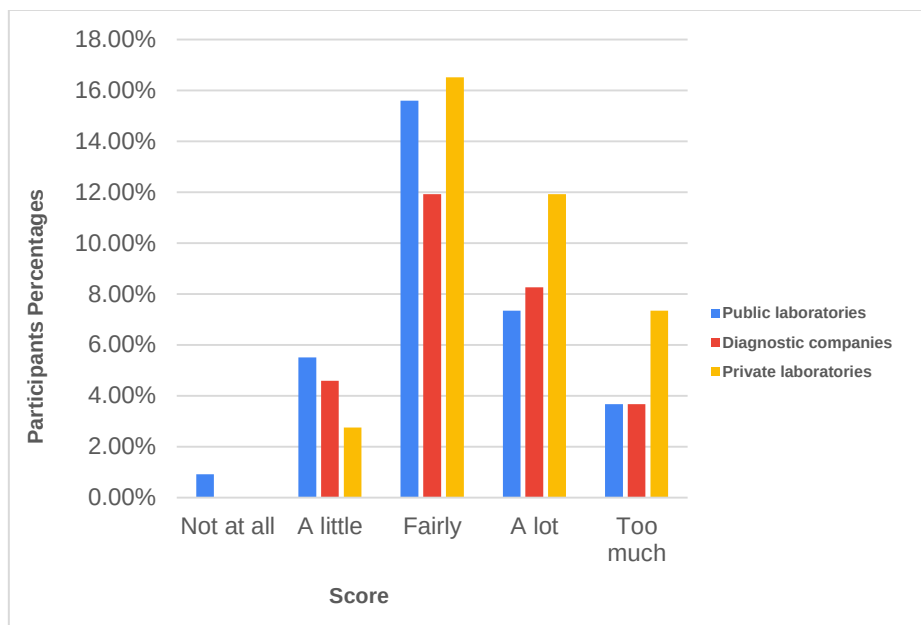


The response of the public proves that saving space is an important advantage of the laboratory as it creates the conditions for its utilization and exploitation, for further laboratory activities. In addition, it can be used to install additional analytical systems resulting in reduced sample processing and result delivery time while enabling the laboratory to develop a full test menu that processes new biomarkers and test methodologies.

Especially the public of private laboratories is characterized by its warm response regarding the saving of space as an important criterion for choosing an analytical unit (diagram 37). 80.55% of the public sector, 92.86% of the private sector and 92.86% of diagnostic companies are classified in the category from 'fairly' to 'Too much'. The percentages with a score from 'A lot' to 'Too much' are 33.33% for the public sector, 50% for the private sector and 41.93% for companies in the health diagnostic sector.

Chart 37.

The size of the analytical unit as a decision criterion



The total cost of ownership is an added value for the laboratory as stated by 94.5% of the respondents on a scale from 'fairly' to 'Too much' (Chart 38).

Chart 38.

The adoption of TCO in the selection criteria is an added value for the laboratory

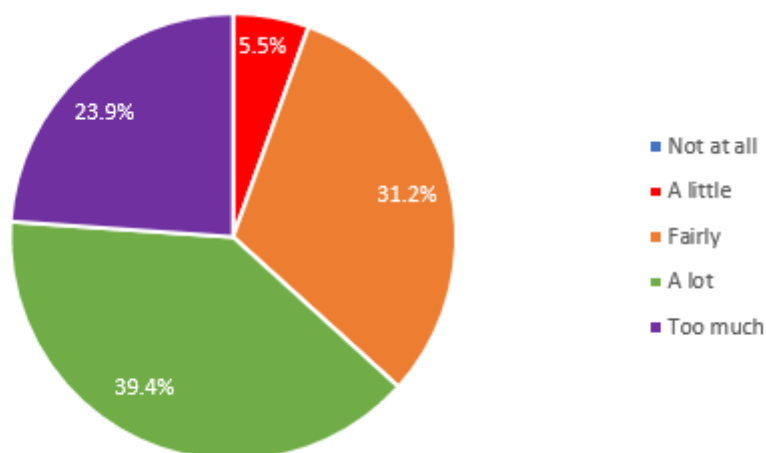
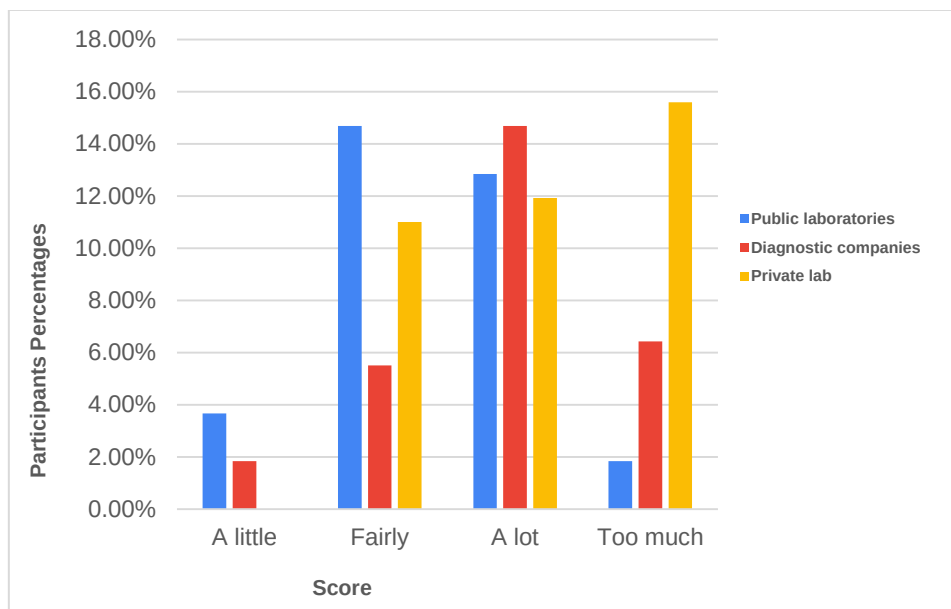


Chart 39.

TCO as additional value in different health sectors

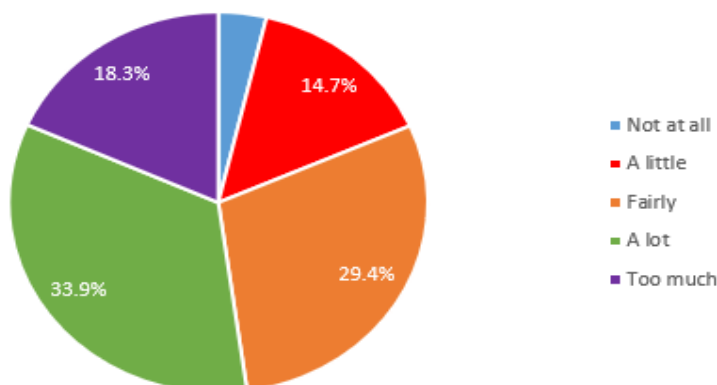


The total cost of ownership is recognized as an added value as shown in Chart 39 with a rating from '*fairly*' to '*Too much*' with percentages of 88.89%, 100%, 93.54% in public, private and diagnostic health sector respectively. With a rating from '*A lot*' to '*Too much*' they answered with percentages of 71.93%, 74.19%, 44.45% in private, diagnostic and public sector respectively.

In addition, the terms included in the contracts for maintenance, repair of the equipment, additionally participate in the total cost of ownership TCO as highlighted by the audience with their answers (Chart 40).

Chart 40.

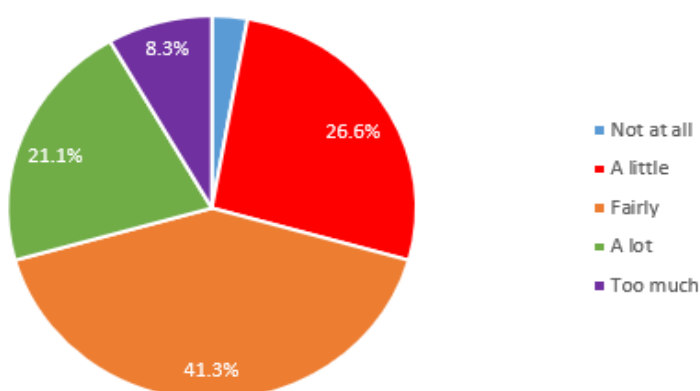
The terms in the maintenance contracts



The arrangement and organizational flexibility offered by TCO can ensure the job satisfaction of the employees in the laboratory based on the responses of the public. However, there is also a significant percentage of 29.4% who do not agree and have their own criteria regarding job satisfaction (Chart 41).

Chart 41.

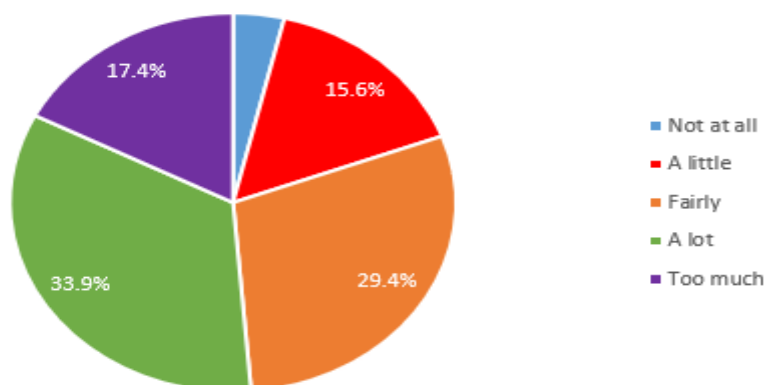
Work satisfaction and TCO



The Total Cost of Ownership model invests heavily in improving TAT (Turnaround time). Reduced results processing times allow for shorter hospital stays and the selection of appropriate treatment protocols (Chart 42).

Chart 42.

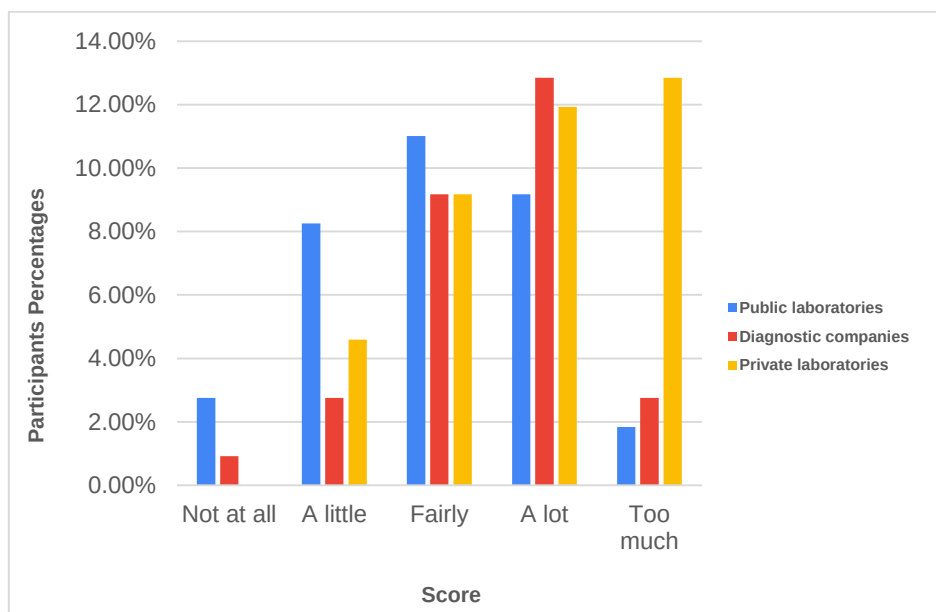
The effect of TCO on the processing time of the results



The following Chart 43 shows the differences in the answers to public, private and health sector professionals. In the public laboratory, 66.67% of respondents rate from 'fairly' to 'Too much' that the effect of TCO on results processing time is critical. Accordingly, in the private sector the percentage is 88.09% while in the diagnostic companies of the sector it is 87.1%. It should be noted that in the question regarding the turnaround time a particularly positive attitude is recorded by the private sector respondents as 64.28 % answers from 'A lot' to 'Too much'. 'A lot' to 'Too much' is chosen by approximately half of the health professionals of diagnostic companies (54.84%), while the corresponding percentage in public laboratories is smaller compared to the rest of the sectors and approaches 33.34%.

Chart 43.

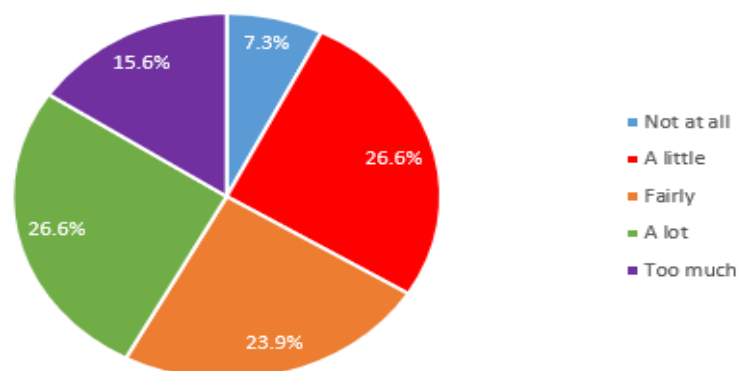
Effect on Turnaround time



A percentage of 66.1% from '*fairly*' to '*Too much*' believe that quality management, including internal and external quality control as well as accreditation of tests with ISO 15189 standards could ultimately in practice reduce the overall cost for laboratory (Chart 44).

Chart 44.

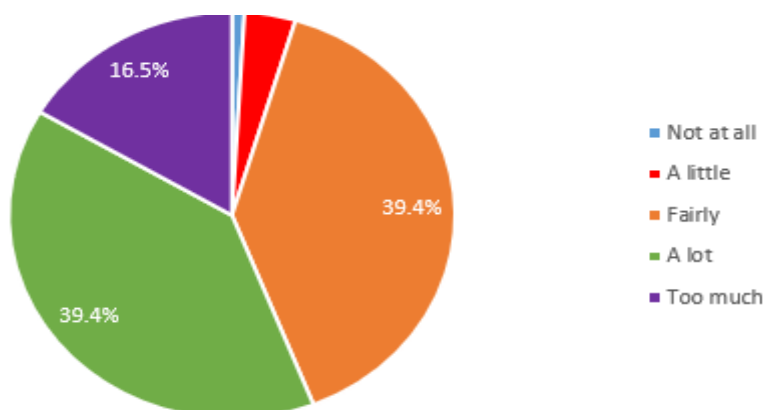
Management based on standards and quality control



It is considered necessary to implement standardization protocols of laboratory and non-procedures within the framework of TCO in order to optimize the workflow. It is necessary to develop and adhere to staff guidance standards (Chart 45). Respondents who have the opposite opinion are expressed with zero percentages.

Chart 45.

Standardization protocols within TCO



In the context of the questionnaire, it was requested to give the value - with values from 1-5 corresponding to a scale from 'Not at all' to 'Too much' - corresponding to the parameters in table 12. Some of the most important criteria of the total cost of ownership are set to be evaluated in the table below, regarding the rating of the TCO parameters.

Table 12.

Rating of the value of the parameters that determine the total cost

Value of TCO parameter	Not at all=1	A little=2	Fairly=3	A lot=4	Too much=5
Cost of purchase of analyzer	1	7	38	33	30
Price of reagents and consumables	1	2	21	50	35
Power consumption	3	16	42	30	18
Possible deionized water production systems and the relative water consumption	0	20	44	29	16
The quality of assays (dilutions, repetitions, reliability)	1	5	13	34	56
Waste production	1	26	42	26	14
Optimal Inventory Management	0	15	31	41	22
Standardization of procedures	2	11	22	43	31
Turnaround time	5	8	16	30	50
Analytical unit processing speed	3	11	14	36	45

The numerical values of table 12 represent the number of respondents in absolute value and their scores in the variables of the table.

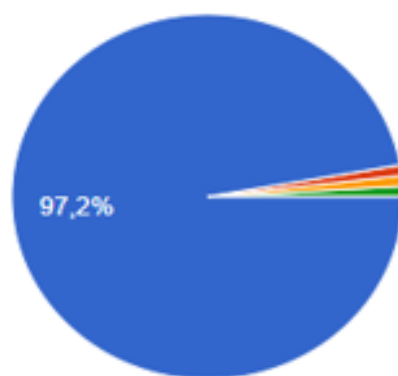
The purchase cost of the analyzer as well as the pricing remain traditionally calculable parameters. With a score of 3 ('Fairly') the cost of possible water production systems and its consumption, the electricity consumed by the analyzer, the generation of waste and the purchase cost of the analyzer are selected by the public. With a score of 4 ('A lot') in the value of the parameter we distinguish the prices of reagents and consumables, the quality of the tests, the optimal inventory management, the standardization of the procedures, the processing speed of the analytical unit with most people choosing the pricing. With a score of 5 ('Too much') we can distinguish the quality of the exams, the expected time of receiving the results, the processing speed of the analytical unit, the pricing with a significant majority of the 56 respondents choosing as the first value the quality of the exams that offers the analytical platform.

The specific responses are dominated by ratings of 3,4,5 in the TCO criteria, which indicates that the public understands the benefits to a maximum extent and appears willing to apply the logic of TCO in the formulation of strategic decisions related to the choice of an analytical platform.

The majority of the public 97.2% in the final question of the survey (chart 46) accept that the total cost of ownership is the most effective approach in the process of selecting analytical units in an in vitro laboratory.

Chart 46.

Agreement on the effectiveness of the TCO approach



5. Discussion

The overall evaluation in the questions of the personal research study is shown in the form of percentages, in the following tables 13-16.

Table 13.

Overall question evaluation rates

Questions	Not at all	A little	Fairly	A lot	Too much
Is the financial cost exclusively (reagents, consumables, equipment pricing) the main factor that will determine the choice of equipment for in vitro laboratory?	1,8%	17,4%	53,2%	20,2%	7,3%
What is the importance of the indirect costs arising from the choice of analytical platform?	2,8%	11%	45,9%	22,9%	17,4%
Could the total TCO cost be affected by the quality of the assays offered by the analyzer?	0,9%	2,8	25,7%	45,9%	24,8%
Do you think that the reliability of patient results is a parameter for determining the total cost by	0,9%	1,8%	21,1%	39,4%	36,7%

the laboratory?					
Could choosing new lab equipment based on total cost of ownership (TCO) optimize the lab's budget?	0%	2,8%	37,6%	39,4%	20,2%
The linearity of the assays to what extent do you think it could affect the cost?	0,9%	15,6%	42,2%	36,7%	4,6%

Table 14.

Overall question evaluation rates (continued)

Questions	Not at all	A little	Fairly	A lot	Too much
What is the effect of total cost of ownership TCO on outpatient or inpatient hospital stays?	4,6%	20,2%	33%	28,4%	13,8%
Could the total cost of ownership TCO contribute to the hospital budget?	0%	3,7%	41,3%	34,9%	20,2%
What percentage (%) of the total cost of ownership resulting from the choice of analytical system could contribute to the overall budget of the healthcare organization you work for?	18 individuals answered 0-20%	24 individuals answered 20-60%	28 individuals answered 40-60%	30 individuals answered 60-80%	9 individuals answered 80-100%
Is the efficiency of the laboratory affected by the downtime (either due to mechanical problem or due to maintenance) of the analyzers?	1,8%	9,2%	26,6%	19,3%	43,1%
Does operator training contribute to the efficient operation of the laboratory?	0%	0%	4,6%	31,2%	64,2%
To what extent could the quality of examinations positively affect the budget of the health care organization?	0%	5,5%	17,4%	42,2%	34,9%
The production quantity of the waste and consequently its subsequent inactivation and deactivation could influence your decision in choosing the analytical Platform?	0,9%	30,3%	39,4%	19,3%	10,1%

Table 15.

Overall question evaluation rates (continued)

Questions	Not at all	A little	Fairly	A lot	Too much
Do you think that the reduction of waste to be processed increases the environmental footprint as well as the reputation of the laboratory?	1,8%	10,1%	39,4%	24,8%	23,9%
Do you consider total cost of ownership TCO acceptable as an informed approach to calculating total cost?	0%	2,8%	33%	35,8%	28,4%
Do you consider that the difference coming from the analysis of the direct economic cost to be significant from the corresponding analysis of the total TCO cost, which also contains the indirect costs?	0%	8,3%	41,3%	37,6%	12,8%
Rate total TCO below as an indicator of growing the laboratory's reputation in the hospital and in the wider healthcare field	0%	16,5%	26,6%	39,4%	17,4%
To what extent do you think saving space could improve the lab's performance KPI?	0,9%	12,8%	44%	27,5%	14,7%
Please rate total cost of ownership TCO as added value to the lab	0%	5,5%	31,2%	39,4%	23,9%
Are the terms included in the maintenance, repair contracts of the equipment also included in the total cost of ownership TCO?	3,7%	14,7%	29,4%	33,9%	18,3%

Table 16.

Overall question evaluation rates (continued)

Questions	Not at all	A little	Fairly	A lot	Too much
From the application of the total cost of TCO could we have work satisfaction of the Lab employees?	2,8%	26,6%	41,3%	21,1%	8,3%
To what extent could the total cost of ownership (TCO) improve the TAT (Turnaround time) and consequently more immediate diagnosis?	3,7%	15,6%	29,4%	33,9%	17,4%
Could quality management that includes internal and external quality control as well as test accreditation actually reduce overall costs for the laboratory?	7,3%	26,6%	23,9%	26,6%	15,6%
Would adopting the philosophy of total cost of ownership TCO result in prompt and reliable diagnosis leading to patient satisfaction?	3,7%	15,6%	38,5%	28,4%	13,8%
Does the implementation of laboratory and non-process standardization protocols within TCO optimize workflow?	0,9%	3,7%	39,4%	39,4%	16,5%

Deactivation of analyzers increases the turnaround time (TAT) and results delivery and consequently creates deterioration in the clinical services and operations of the healthcare organization. At the same time, the reputation and credibility of the laboratory as a provider of patient test results within the health organization is degraded.

Terms contained in the contracts must be related to clauses, with a twenty-four-hour support agreement, with time limitations regarding the repair of the analyzers. An important role is also played by the renegotiation of the terms of the contract after a time-determined frequency so that the age of the equipment is also taken into account. Optimizing clinical engineering tasks can deliver high equipment utilization and support the organization's financial goals (Hockel, D. et.al,2014). The total cost of ownership (TCO) in this case is used to ensure that all costs derived from clinical engineering over the lifetime of the analyzers are taken into account (Trimedx,2014).

The reliability of the patient results is directly related to the sensitivity and specificity specifications of the assays, to their methodology, to the reduction of interference from substances chemically related to the substance to be analyzed or from endogenous factors related to the quality of the samples (effect factors: hemolysis, lipemia, jaundice) as well in the functional reliability of the analysis instrument. The reliable assay results produced by the in vitro laboratory determine the medical decisions resulting in reducing the costs of the health organization in services, the administration of pharmaceutical material and the hospitalization of the patients while highlighting the value of the laboratory. The quality of assays, the use of appropriate biomarkers limits the hospitalization of patients and create the conditions for effective treatments and the reduction of drugs provided to patients. Many of the screening tests required for preventive care show that laboratory results are vital for monitoring the progression of a disease and the effectiveness of its treatment (Futrell,2015). Laboratories must create additional clinical value (Futrell,2015).

All the diagnostic companies that offer analytical in vitro systems use the space as an additional element of marketing in order to influence the decisions of the managements of the laboratory and more broadly of the health organization. They promote analytical systems that have multiple built-in functions and define the processing speed of the analyzer per square meter giving due importance to this critical TCO factor.

The representatives of the diagnostic companies play an important role when the promotion of their products is inspired by the philosophy of adopting the total cost of ownership, as a result of which they form a different framework of competitiveness and 'educate' those to whom the equipment is addressed with more realistic selection criteria. Hidden costs must be discovered and considered in strategic biomedical equipment procurement decisions. Otherwise, unpredictable conditions are created for the laboratory. Assuming that laboratories wish to obtain the greatest financial benefit, then this benefit will be based on factors such as the credibility of the argument, the timing of their cash flows and their alignment with the supply of total cost of ownership. Going forward, new product pricing decisions will have to follow a value-creating model that strictly adheres to the TCO

methodology. Total cost of ownership calculations will be about quantifying the total value created for the laboratory. Laboratories value creation can take many forms: increased revenue, increased price premium, reduced risk, reduced working capital or fixed capital investment, or any other level that positively affects their profitability (Snelgrove, 2011).

TCO creates additional value and benefits for the laboratory because it highlights the qualitative and quantitative characteristics of the biomedical equipment that will affect the efficiency of the in vitro laboratory.

6. Conclusions

The TCO methodology associated with improved financial targets, operational lab productivity cost reduction, optimization quality and workflow, enhanced clinical value for patients.

TCO can ensure that a laboratory achieves operational efficiency and creates greater value not only for the laboratory but for the healthcare organization (Berwick et. al., 2008).

The financial analysis you perform with the analytic platform lifecycle model and Total Cost of Ownership (TCO) theory, allows institutions to have more information and therefore fundamentally change a decision that was previously made with less information. It is important to note that hidden costs should also be taken into account by the health care institution. This implies significant increases in investment in new technologies. It is recommended that the TCO process evolves into a key award criterion when conducting health technology assessment and procurement, thus aiding long-term strategic decision-making.

Advanced companies in many industries support the investment they make in developing new products and creating value for customers. Supporting value pricing and sales with the right tools, processes and people enables a high value product to be presented to customers so that they see, realize and understand the reasoning behind the premium price and are willing to pay for it.

Incorporating the concept of TCO into daily work can be a significant change for most healthcare organizations and laboratories, as it requires rethinking value beyond simple cost. It is not just a methodology it is a mindset change and a catalyst in a rapidly changing competitive environment.

Berwick et. al. (2008) state that improvement initiatives pursue a broader system of linked goals that is called the “Triple Aim”. It includes improving the individual experience, improving the health of populations through medical care, and reducing the per capital cost of care for populations.

The elements of the Triple Aim are not independent of each other. Changes pursued in either goal may affect the other two, sometimes negatively and sometimes positively. For example, improving care for individuals may increase costs if the improvements are

associated with new, effective, but expensive technologies or drugs. Conversely, eliminating the overuse or misuse of treatments or diagnostic tests can lead to both reduced costs and improved outcomes. The situation is further complicated by the time lags between the effects of the changes.

From an economic point of view, the fact of acquiring technology with a certainty of lower life cycle costs, confirms the importance of conducting a comprehensive analysis that includes technical, after-sales aspects, patient safety, factors of vital importance in making a decision to invest in biomedical technology.

The diagnostic company that will be able to document the greatest surplus value will be the one that will have the lead in the offers that will be made for the laboratory equipment. It is the total added profit, which refers to the total benefits, risks, costs and opportunities, created by adopting the total cost of ownership philosophy.

The fact of acquiring technology with certainty of lower life-cycle costs, confirms the importance of conducting a comprehensive analysis that includes technical, after-sales aspects, patient safety, factors vital to making a decision to invest in biomedical technology. By applying the total cost of ownership TCO methodology, you investigate the total cost of control processes and make key metrics that allow lab managers to identify operational efficiency opportunities and use their findings and data for feedback and alignment in order to think developmentally about the future of their labs.

TCO is a holistic measure of value that takes into account not only cost savings but also laboratory performance improvements, risk reduction, increased revenue and patient-customer satisfaction.

References

- Aissaoui, N., Haouari, M. and Hassini, E. (2007). "Supplier selection and order lotsizing modeling: a review", *Computers and Operations Research* , vol.34, no.12, pp. 3516–3540.
- Anderson, S. W. and Young, S. M. (1999). "The impact of contextual and process factors on the evaluation of activity based costing systems", *Accounting, Organizations and Society*, vol. 24, pp. 525–559.
- Balogh, E., Miller, B. and Ball, J.R. (2015). *Improving Diagnosis in Healthcare*, Washington (DC): National Academies Press, Committee on Diagnostic Error in Health Care; Board on Health Care Services; Institute of Medicine; The National Academies of Sciences, Engineering, and Medicine.
- Barreneche, J.G. , Hernández, A.M. and García, J.H. (2015). "Analysis of Total Cost of Ownership (TCO) Applied to Processes of Biomedical Technology Acquisition Competitive Intelligence", *Pan American health care exchanges conference and workshops and exhibits*, university of Antioquia, Medellín, Colombia, 23-28 March 2015, Santiago, Chile.
- Berwick, D.M, Nolan,T.W and Whittington,J. (2008). "The Triple Aim: Care, Health, And Cost", *Health Affairs*, vol. 27, no.3, May 2008, pp.759-769.
- Dabbs, T. (2017). Optimizing Total Cost of Ownership (TCO), Plant Performance Services Group, ITT, 2017. Available: <https://edelmann.com/wp-content/uploads/Pump-Pricing-Total-Cost-of-Ownership-TCO.pdf>
- Ellram, L. M. (1995). "Total cost of ownership: An analysis approach for purchasing", *International Journal of Physical Distribution and Logistics*, vol.25, no.8, October 1995, pp. 4-23.
- Emerald publishing (2022).Addressing the issues of management and quality, International Journal of Health Care Quality Assurance [online], vol.35, issue1. Available : <https://www.emerald.com/insight/publication/issn/0952-6862/vol/35/iss/1>

- Forsman, R.W. (1993). "Why is the lab an afterthought for managed care organizations?", *Clin Chem*, vol 42(5), pp.813-816.
- Francis, A.J., Ray, M.J. ,Marshall, M.C.(2009). "Pathology processes and emergency department length of stay: the impact of change", *Med J Austral*, vol 190 (12), June 2009, pp.665–9. DOI: [10.3390/s22134968](https://doi.org/10.3390/s22134968) PMC9269793 [PUBMED]
- Futrell, K. (2015). "The Value of the Laboratory in the New Healthcare Model. Diagnostic Information: The New Currency in the Future of Healthcare", *Orchardsoftware*, July 2013, pp.3-23. [https://cdn.clpmag.com/clpmag/2013/08/Orchard The Value of the Lab.pdf](https://cdn.clpmag.com/clpmag/2013/08/Orchard%20The%20Value%20of%20the%20Lab.pdf) (accessed on 7 April 2023)
- Garcia, J.H. and Hernandez, A.M. (2013). "Biomedical Technology Assessment in Health Care Centers: A Systems Approach", *2013 Pan American Health Care Exchanges(PAHCE)*, IEE, Medellin Colombia, 29 April 2013 - 4 May 2013. DOI: [10.1109/PAHCE.2013.6568313](https://doi.org/10.1109/PAHCE.2013.6568313)
- Gontard&Cie Group. Geneva, Moscow, Dubai (2018).
- Heilala, J., Helin, K. and Montonen, J.(2006). "Total cost of ownership analysis for modular final assembly systems", *International Journal of Production Research*, 44(18-19), pp. 3967–3988. DOI: [10.1080/00207540600806448](https://doi.org/10.1080/00207540600806448)
- Hernández, A., Ruiz, L., Duque, C., Álzate, J. and García, j. (2010). "Model for the evaluation of biomedical technology and its application in the acquisition of equipment for a Colombian public hospital", *Congress of Latin America in biomedical engineering*, Cuba, 2010. DOI: [10.1109/PAHCE.2015.7173325](https://doi.org/10.1109/PAHCE.2015.7173325)
- Hockel, D. and Hamilton, T. (2011)'Understanding total cost of ownership', *Healthcare Purchasing News*, 35 (9), 2011. PMID: 24968636 [PUBMED]
- Hospodková, P. and Vochyánová, A. (2018). "The Application of the Total Cost of Ownership Approach to Medical Equipment—Case Study in the Czech Republic", *World Congress on Medical Physics and Biomedical Engineering 2018*, Faculty of Biomedical Engineering,

Czech Technical University in Prague, vol. 68(3), 30 May 2018, pp. 361-366.
DOI: [10.1007/978-981-10-9023-3_65](https://doi.org/10.1007/978-981-10-9023-3_65)

Kanagaraj, G. and Jawahar, N. (2009). “A simulated annealing algorithm for optimal supplier selection using the reliability-based total cost of ownership model”, *Department of Mechanical Engineering Thiagarajar College of Engineering Madurai Int. J. Procurement Management*, vol.2, no.3, India 2009.

Li, L., Georgiou, A., Vecellio, E., Eigenstetter, A., Toouli, G., Wilson, R. and Westbrook, J.I. (2015) ‘The effect of laboratory testing on emergency department length of stay: A multi hospital longitudinal study applying a cross-classified random effect modeling approach’, *Academic Emergency Medicine*, vol 22(1), 22 January, pp.38-46. DOI: [10.1111/acem.12565](https://doi.org/10.1111/acem.12565) [PUBMED]

Martinko, K. (2010). “How Understanding the Total Cost of Ownership of Your Equipment or Instrumentation Can Reduce Costs, Increase Performance and Improve Workforce Productivity”, *Thermo Fisher Scientific Inc.*, Scientific Instruments Division, Madison, 2010, Application Note: 01004.

Matthew J. Liberatore (2013). “Six Sigma in healthcare delivery”, *Villanova School of Business, Villanova University*, Pennsylvania, USA, vol. 26(7), 9 September 2011, pp.601-26.

Morfonios, A., Kaitelidou, D., Filntisis, G., Baltopoulos, G., Str, P., Myrianthefts, P. (2014). “Economic Evaluation of Multislice Computed Tomography Scanners Through a Life Cycle Cost Analysis”, *Indian Journal of Applied Research*, vol. 4, pp. 158–161.

National Center for Education Statistics (2014). Total Cost of Ownership: An Important Piece of Any Sustainability Plan, National Center for Education Statistics [online], April 2014. Available: <https://nces.ed.gov/programs/slds/pdf/TotalCostofOwnership.pdf>

Nisreen, H.J., Salloom, A.J., Omer, N.M. (2015) ‘Medical Devices Service Life Cycle Cost Management in Al Karak Hospital as a Case Study’, *Journal of Accounting & Marketing*, vol. 4, pp. 2–9. DOI: [10.4172/2168-9601.1000134](https://doi.org/10.4172/2168-9601.1000134)

Nucleus Research, Inc. (2007). The Strengths and Weaknesses of Total Cost of Ownership, Case studies Nucleus Research [online], 2007. Available: <http://www.nucleusresearch.com/research>

PINNACLECARE (2016). The Human Cost and Financial Impact of Misdiagnosis', PinnacleCare [online]. Available: <https://www.pinnaclecare.com/download/Human-Cost-Financial-Impact-Whitepaper.pdf>

Snelgrove, T. (2012). The total cost of ownership vision. In: Industrial Equipment Insight, in Accenture (ed.), 2001. Available: https://img1.wsimg.com/blobby/go/80ffbeb0-74f1-4712-b7fa-108f131e0083/downloads/1c51atrm9_602692.pdf

Snelgrove, T. (2011). "Value pricing when you understand your customers: Total cost of ownership – Past, present, and future", SKF USA Inc., Revised form: 16th September 2011. DOI: [10.1057/rpm.2011.35](https://doi.org/10.1057/rpm.2011.35)

Storrow, A.B., Zhou, C., Gaddis, G., Han, J., Miller, K., Klubert, D., Laidig, A. and Aronsky, D. (2008). "Decreasing lab turnaround time improves emergency department throughput and decreases emergency medical services diversion: a simulation model", *official journal of the Society for Academic Emergency Medicine*, vol. 15, 1 November 2008, pp. 1130–5. <https://doi.org/10.1111/j.1553-2712.2008.00181.x> (accessed on 20 April 2023)

Total value of ownership (2018), April 2018, Abbott Laboratories.

Trimedx (2014). "Total cost of Ownership: The influence of Clinical Engineering", *white paper Indianapolis*, Engineering and Consulting services company specialized on Clinical Engineering and asset management and Cybersecurity, USA. <https://www.trimedx.com/resource/trimedx-clinical-asset-management>

Wouters, M., Anderson, J. and Wynstra, F. (2005). "The adoption of total cost of ownership for sourcing decisions—a structural equations analysis", School of Business, Public Administration and Technology, University of Twente b Kellogg School of Management, Northwestern University, USA c Erasmus Research Institute of Management, Erasmus University, Rotterdam, The Netherlands, *Accounting, Organizations and Society*, ELSEVIER, vol. 30 (2005), pp. 167–191.