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Article

Model to Measure the Readiness of University Testing Laboratories to Fulfill ISO/IEC 17025 Requirements (A Case Study)

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Abstract: Universities are considered as a source of open innovations by producing new technology. The innovations need to be tested in licensed laboratories in order to create certified products if they are to be commercialized to the market. Many universities have established laboratories that provide testing services to society and act as a revenue-generating source. Universitas Sebelas Maret (UNS) owns an accredited center laboratory that provides testing services to external parties. In addition, the university owns other laboratories in several faculties to conduct academic activities and research and yet provide testing services, but have not been accredited. Therefore, the laboratories have the potential to be developed as part of the testing service business to support the incubation process of new technology and provide testing services. In this article, we chose UNS, one of the universities in Indonesia, to develop a framework of readiness level measurement instrument, to evaluate the readiness and to suggest improvements for laboratories to achieve accreditation. A framework of laboratory readiness measurement was developed using integration of management approach and laboratory approach. Descriptive statistics were used to create a radar chart to determine the readiness level. Based on findings and evidence analysis, we proposed improvement planning using ISO 17025 and management concept.

Keywords: assessment framework; innovation; ISO/IEC 17025; readiness level; university testing laboratories

1. Introduction

Universities have played a key role in the technological, economic, and social development of countries by producing innovations and inventions through research done by academics [1–3] to perform the role of research and development to create new technology [4,5]. In other words, universities are considered as an open innovation source as a result of the research activities [6–18]. Recently, there has been rapid progression in technology [19–21] and the industrial sector [22–24]. Lots of product innovations in these sectors resulted from universities, for instance, lithium battery [25–27], electric vehicle [28,29], and traceability technology [30,31]. The innovations would be more beneficial if they were followed by commercialization. Prior to commercialization, eligible product testing in licensed laboratories is needed to create certified products [32–34]. Due to the product innovation acceleration, the provision of laboratories has been insufficient. Thus, these factors urge universities to establish laboratories [35–37] to perform the role of testing services provider [38–42] aside from the original purpose of teaching and research laboratories [43–52].

Nowadays, it has been pretty notable for universities to accomplish revenue generation in order to maintain their sustainability [3,53]. Providing services in their laboratories to perform tests for external parties can be a means to gain revenue and support the incubation process of new technology [53]. Laboratories that provide testing services must be accredited and comply with the laboratory standard (i.e., ISO/IEC 17025) to ensure their competency in performing tests [54]. ISO/IEC 17025 is a laboratory standard that contains general requirements of laboratory competence in conducting testing and/or calibration. It includes the quality management system and technical requirements of the accreditation process [55]. There are several benefits laboratories can gain by fulfilling this standard, such as the ability to produce consistent results and more satisfying performance [56], overall improvement of laboratory business [57], the ability to prove the reliability of test results and technical competence to customers [58], and enhanced competitiveness in the market by improved quality, reliability, accuracy, and consistency of products, services, and processes [54].

Indonesia is one of the countries that strive to develop World Class Universities (WCUs) [59], one of whose goals is having adequate facilities and funding [60]. Sustainable and accountable financial support is needed to reach this goal [61]. Therefore, generating revenue from a university's internationally standardized business units is an initial step that can be taken to create world-class funding [62]. Exploiting university laboratories to provide services may be a reliable move to perform this role.

Universitas Sebelas Maret (UNS) is a university in Indonesia which is pursuing WCU status. As a key step to accelerate towards this status, the university has established some business units, one of which is a center laboratory which has been accredited based on ISO 17025. This laboratory provides testing services to external parties and has been successfully running the business, having many customers [63]. Other than the center laboratory, the university has 13 laboratories located in 3 faculties which are basically used for academic activities and yet provide testing services. However, the laboratories do not comply with testing laboratory accreditation qualifications. Besides, the university laboratories are basically research laboratories that do not have good management practices although they are expected to be product certification agencies. In addition, to support the commercialization of a university's innovation product in the market, the technology readiness level of the product has to be measured first and certified by the product certification agency [64,65]. Thus, those laboratories have potential to be developed as standardized testing laboratories. With regards to WCU status, it is important for the university to establish a testing service business within the university by integrating the center laboratory and those potential laboratories to expand revenue generation and support the commercialization of new technology so that the innovation of new technology can be introduced to the market.

Each laboratory in each faculty (i.e., Faculty of Science, Engineering, and Agriculture) has a different core competence. It means that each laboratory can provide services by offering different kinds of tests and parameters. In daily practice, the laboratories have been operating independently in terms of performing testing services. In other words, there has not been interactive relationship-building between them. However, interorganizational linkages are likely to become important when an organization strives to establish a new business ecosystem [66]. Therefore, an appropriate strategy is required to support the interorganizational relationship between laboratories in the testing service ecosystem in the university.

It is important that the university improves the quality of the testing service business to commercialize the innovation product. It means that the quality of the potential laboratories needs to be improved. Implementing an ISO/IEC 17025 quality management system is an initial step that could be done to improve the laboratories' quality [67]. To accomplish this goal, the potential laboratories must be transformed into licensed laboratories by fulfilling ISO 17025 accreditation requirements. Therefore, this study aims to develop a framework to measure the readiness level of the potential laboratories to be developed as part of the testing service business by considering ISO 17025 requirements and organizational audit factors.

There have been many researchers studying about the readiness level of a system. Sutopo et al. [68] developed a framework to measure university readiness for establishing spin-offs considering the optimal time that is used to launch a spin-off company. Lokuge et al. [69] conceptualized a formative multidimensional construct to gauge organizational readiness for digital innovations. Kobos et al. [70] developed Regulatory Readiness Level (RRL) and Market Readiness Level (MRL) frameworks towards technology development to meet desired technical and policy goals in the coming decades. There also has been much research regarding ISO 17025. Rodima et al. [71] described the benefits that a university can gain from having an ISO 17025 accredited quality system in place. Meanwhile, Hullihen et al. [72] discussed experience in establishing an ISO 17025 compliant laboratory at a university and Zapata-Garcıa et al. [73] presented the experience of implementing a quality system on ISO 17025 for the accreditation of a university testing laboratory. Moreover, organizational audit factors are used as parameters to assess strengths and weaknesses of the organization and generate strategies upon the findings [74–77].

In this article, we aimed to develop an instrument to measure the university laboratories' readiness level. Based on the readiness level evaluation, we proposed improvements for the laboratories in order to achieve accreditation. The improvements of the laboratories are expected to support the commercialization of new technology in the market.

The remainder of the paper is organized as follows: Section 2 presents the methodology employed to generate the framework. Section 3 shows the result of implemented framework and presents the descriptive statistics. Section 4 discusses the result including the findings and interpretations of it. Section 5 concludes by summing up the work.

2. Methods

2.1. Designing Laboratory Readiness Measurement Instrument

In this section, we presented the stages and approaches taken to generate a questionnaire. This questionnaire was used as an instrument to measure the laboratory readiness level in fulfilling ISO/IEC 17025 requirements. The instrument designing consisted of two stages, as follows.

2.1.1. Generating Sets of Matching Criteria, Subcriteria, and Activities

At this stage, we reviewed and integrated two researches as a benchmark. Organizational audit factors, which were derived from David's research [78], consist of criteria and subcriteria used in conducting internal audits in an organization. Those factors were used to assess the laboratory's internal environment situations. Meanwhile, the research of Grochau & Caten [79] was used to determine the process elements involved in providing testing services in the laboratory. Based on this research [79], we derived the activities involved in each process element along with corresponding standard items regulated in ISO/IEC 17025. The next step was comparing the criteria and subcriteria of organizational audit factors with the processes and activities elements in conducting testing services in the laboratory. This step aimed to distribute activities in the provision of laboratory testing services to matching subcriteria. The results of this approach are shown in Table 1.

Table 1. Organizational audit factors and laboratory's testing service activities distribution.

Criteria	Subcriteria	Activities	Process Element	Standard Item in ISO 17025
Management (C1)	SC1-Planning	Formulate policies and objectives of the quality management system	Policies and procedures planning	4.2
	SC2-Organizing	Meet organizational requirements	Management responsibility	4.1
	SC3-Staffing	• Hire, train, evaluate, and authorize staff • Describe the functions and responsibilities of personnel	Personnel management	4.1, 5.1, 5.2
	SC4-Controlling	• Record and solve complaints	Complaint	4.8
		• Record and analyze nonconformities • Plan and implement corrective actions • Ensure corrective and preventive actions	Nonconformity, corrective, and preventive actions	4.9, 4.10, 4.11, 4.12
		• Plan, implement, and record internal audits	Audits	4.10, 4.14
		• Plan, implement, and record meetings regarding management reviews	Management responsibility	4.10, 4.15
Marketing (C2)	SC5-Service sales	• Contact the client • Determine requirements • Make agreements regarding methods, prices, and deadlines • Formulate a contract	Review requests, tenders, and contracts	4.4
Marketing (C2)	SC6-Service planning	• Providing appropriate access to the laboratory • Provide guidance for preparation, packaging, and shipping of test samples • Maintain communication throughout the process • Looking for feedback through customer satisfaction surveys	Customer service	4.7
Operation (C3)	SC7-Resources	• Collect, receive, identify, control, protect, and receive goods tested • Implement or subcontract testing • Analyze test data • Record, protect, and send test reports	Testing	5.8, 4.5, 5.10
		• Evaluating suppliers • Maintain approved suppliers • Develop requirements for purchasing activities • Carry out purchasing activities • Checking items received with the desired specifications	Purchasing	4.6
		• Supervise, control, and record environmental conditions • Adjust laboratory facilities, control access, and use of laboratory areas	Infrastructure	5.1, 5.3
		• Study, create, validate applying and use testing methods and related procedures • Estimating measurement uncertainty	Method	5.1, 5.4

Table 1. *Cont.*

Criteria	Subcriteria	Activities	Process Element	Standard Item in ISO 17025
Operation (C3)	SC7-Resources	• Study, identify, supervise, maintain, and calibrate equipment • Outlines procedures for maintenance, transfer, storage, safe use, and scheduling maintenance of measurement equipment	Equipment	5.1, 5.5
	SC8-Quality	• Develop programs and procedures for equipment calibration and standard setting • Participate in a collaborative study program or testing expertise and analyzing laboratory performance	External quality control	5.1, 5.6, 5.9
Operation (C3)	SC8-Quality	• Provides intermediate checks to maintain confidence in the calibration status of the tool and reference standards • Develop comparisons in the laboratory • Establish quality control procedures when regular use of reference materials is certified, replicates testing or repeats testing of retained samples • Analyze collected data	Internal quality control	5.5, 5.6, 5.9
Management information system (C4)	SC9-Information system management	• Publish, approve, distribute, and manage quality management system documents • Identify, collect, compile, store, maintain, and tidy up documents related to quality and technical details	Information management	4.3, 4.13, 5.4, 5.10

2.1.2. Generating Sets of Indicators

At this stage, we generated laboratory readiness indicators. We highlighted criteria, subcriteria, process elements, and standard items in the previous stage to be employed in this stage. Furthermore, we referred to the explanations of each standard item in ISO/IEC 17025. The explanations of each standard item in each process element were then summarized into sets of 117 indicators of the instrument. The result of this stage is presented in Table 2.

Table 2. Laboratory Readiness Measurement Instrument.

Subcriteria	Indicator
SC1-Planning	1 Determination of management systems 2 Application of management systems 3 Maintenance of management systems 4 Management policy documentation 5 Management system documentation 6 Program documentation 7 Documentation procedure 8 Documentation of work instructions 9 Communication of documentation to all personnel 10 Understanding of documentation by all personnel 11 Availability of documentation for all personnel 12 Application of documentation by all personnel 13 Quality manual 14 Quality objectives 15 Issuance of quality policy

Table 2. *Cont.*

Subcriteria	Indicator
SC1-Planning	16 Laboratory management commitment 17 Management statement for laboratory service standards 18 The objectives of management systems related to quality 19 Requirements for all personnel to understand and implement policies and procedures 20 Commitment to improve the effectiveness of management systems on an ongoing basis
SC2-Organizing	1 Determination of organizational structure and laboratory management 2 Determination of management position within the parent organization 3 Determination of the relationship between quality management, technical activities, and supporting services 4 Determination of responsibility, authority, and relations between all personnel
SC3-Staffing	1 The presence of managerial and technical personnel 2 Division of task management and technical personnel 3 Adequate supervision of testing staff 4 Technical management 5 Quality manager 6 Appointment of deputies for core management personnel 7 Educational qualifications 8 Training qualifications 9 Experience qualifications 10 Skill qualifications 11 Appropriate supervisors to staff undergoing training 12 Formulation of educational goals 13 Formulation of training objectives 14 Formulation of skill targets 15 Personnel training policies and procedures 16 Evaluate the effectiveness of training activities 17 The existence of contract/nonpermanent personnel 18 Maintenance of applicable job descriptions 19 Determination of authority to take samples 20 Determination of authority to conduct testing 21 Determination of authority to issue test reports 22 Determination of authority to give opinions and interpretation of test results 23 Determination of authority to operate certain equipment 24 Documentation of personnel authority 25 Documentation of personnel competence
SC3-Staffing	26 Documentation of personnel education 27 Professional qualification documentation 28 Personnel training documentation 29 Documentation of personnel skills 30 Documentation of personnel experience
SC4-Controlling	1 Determination of policies and procedures for resolving complaints received from customers or other parties 2 Documentation regarding complaints received 3 Documentation related to investigations of complaints received 4 Documentation regarding corrective actions taken 5 Determination of policies and control procedures for inappropriate testing work 6 Increasing the effectiveness of the management system on an ongoing basis 7 Determination of policies and procedures for carrying out corrective actions 8 Determination of preventive action procedures for nonconformity and policy deviation 9 Establishing schedules and procedures for internal audits 10 Periodic internal audits 11 Testing activities are included in the elements that must be audited 12 Planning and organizing audits by quality managers 13 The audit is carried out by trained personnel and independent of the audited activities 14 Schedule and procedures for laboratory management review 15 Periodic implementation of laboratory management reviews
SC5-Service sales	1 Determination and maintenance of customer request review procedures 2 Determination of tender review procedures 3 Determination of procedures for reviewing test contracts
SC6- Service planning	1 Determination of test sampling procedures 2 Determination of procedures for recording test sample data 3 Seek feedback from customers through customer surveys

Table 2. *Cont.*

Subcriteria	Indicator
SC7-Resources	1 Subcontract testing work 2 Reporting on test results 3 Determination of transportation procedures for goods tested 4 Determination of procedures for receiving goods tested 5 Determination of procedures for handling goods tested for deterioration, loss, or damage 6 Determination of procedures for protecting goods tested
SC7-Resources	7 Determination of procedures for storing goods tested 8 Determination of procedures for identifying items tested 9 Recording the condition of items tested when received by laboratory staff 10 Consultation with customers if the goods received are not in accordance with existing specifications 11 Determination of policies and procedures for selecting and buying services and supplies 12 Procedure for purchasing reagents and disposable materials 13 Procedure for receiving reagents and disposable materials 14 Procedure for storing reagents and disposable materials 15 Conduct evaluation towards supplier of disposable materials, supplies, and services 16 Energy source is adequate 17 Lighting is sufficient 18 Adequate environment 19 Procedure for guaranteeing accommodation conditions and laboratory environment 20 Procedure for access to laboratory space 21 Procedure for using laboratory space 22 Use of appropriate methods and procedures for all tests performed 23 Equipment operating instructions 24 Instructions for handling and preparing items tested 25 Procedure for estimating measurement uncertainty 26 Equipment handling procedures 27 Equipment removal procedure 28 Equipment storage procedure 29 Procedure for using tools 30 Equipment maintenance procedures
SC8-Quality	1 Calibration of equipment 2 Equipment calibration programs and procedures 3 Intermediate check 4 Quality control procedures 5 Analysis of quality control data
SC9-Information system management	1 Document control procedures 2 Quality and technical documentation control procedures 3 Internal audit report 4 Management review report 5 Reports on corrective actions 6 Preventive action report 7 Procedure for the protection and backup of records stored electronically
9 total subcriteria	117 total indicators

2.2. Instrument Testing

At this stage, we carried out a survey using the instrument to collect data from 13 faculty laboratories in UNS. The respondents chosen to fill out the questionnaire were the heads of each laboratory. Table 3 shows the details and categories of the surveyed laboratories. The heads of the laboratory were chosen because they knew the best about their laboratory conditions including the management and technical aspects. The respondents were asked to check off the indicators which they had fulfilled.

Table 3. Potential laboratories categories.

Category	Laboratory
Engineering	Material Lab (L2) Nano Bioenergy Lab (L3) Thermodynamic Lab (L4) Structural Lab (L5) Mechanics Lab (L11) Ergonomic Lab (L12) Basic Chemistry Lab (L13)
Agriculture	Soil Fertility Lab (L6) Soil Conservation Lab (L7) Biotechnology Lab (L8) Plant Breeding Lab (L9) Plant Physiology Lab (L10)
Food technology	Food Biochemistry Lab (L1)

3. Results

3.1. Laboratory Readiness Instrument Framework

An instrument for assessing university laboratory readiness to be developed into testing laboratories was generated. This instrument framework consists of four criteria to assess the laboratory's organizational readiness, that is, the laboratory's management, marketing, operation, and management information system. The subcriteria used in assessing the laboratory's management performance were planning, organizing, staffing, and controlling. In addition, two subcriteria were used to assess the laboratory's marketing performance (i.e., selling services and service planning). Moreover, two subcriteria were used in assessing the laboratory's operation performance (i.e., resource and quality). The corresponding processes for each subcriterion are shown in Figure 1. The framework shown in Figure 1 refers to previous work [80].

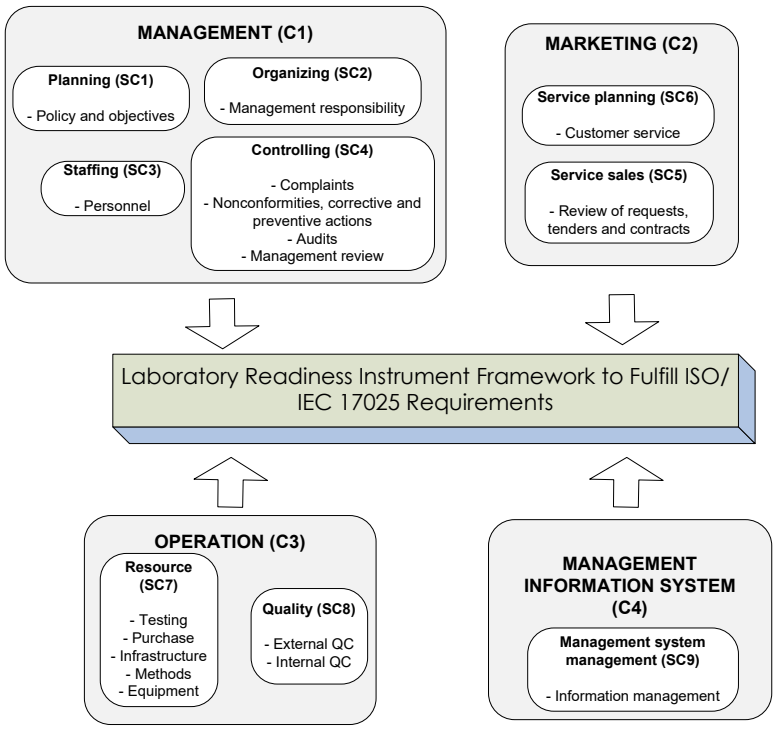

Figure 1. Instrument framework for assessing laboratory readiness.

3.2. Laboratory Readiness Level Measurement

Potential laboratories readiness level was measured by the percentage of indicators fulfilled. At this stage, a recapitulation of the number of indicators fulfilled by each respondent was conducted from a total of 117 indicators. Then, the percentage of indicators fulfilled was calculated by dividing the number of fulfilled indicators with the total indicators in the instrument. Table 4 shows the recapitulation of fulfilled indicators by each laboratory (L).

Table 4. Potential laboratories readiness level.

Laboratory	Total Indicators Fulfilled	Indicators Fulfillment Percentage
L1	46	39%
L2	60	51%
L3	26	22%
L4	56	48%
L5	55	47%
L6	43	37%
L7	45	38%
L8	44	38%
L9	24	21%
L10	25	21%
L11	55	47%
L12	31	26%
L13	25	21%

Next, we assessed the readiness level of each subcriterion by calculating the indicators fulfillment percentage of each subcriterion. The calculation was done by calculating the average percentage value for each subcriterion of the overall 13 laboratories. The result can be seen in Table 5. Figure 3 shows the percentage graph of indicator fulfillment for each subcriterion.

Table 5. Subcriteria readiness level.

Criterion	Subcriterion	Indicator Fulfillment Percentage
Management	Planning	25%
	Organizing	75%
	Staffing	44%
	Controlling	19%
Marketing	Service selling	0%
	Service planning	54%
Operation	Resources	45%
	Quality	12%
Management information system	Information system management	20%

According to Table 5 and Figure 2, based on management aspect, the most ready subcriterion in general was organizing. Meanwhile, for the marketing aspect, in general, the laboratories were best prepared for the service planning subcriterion. While viewed from operation aspect, the laboratories were best prepared for the resources subcriterion.

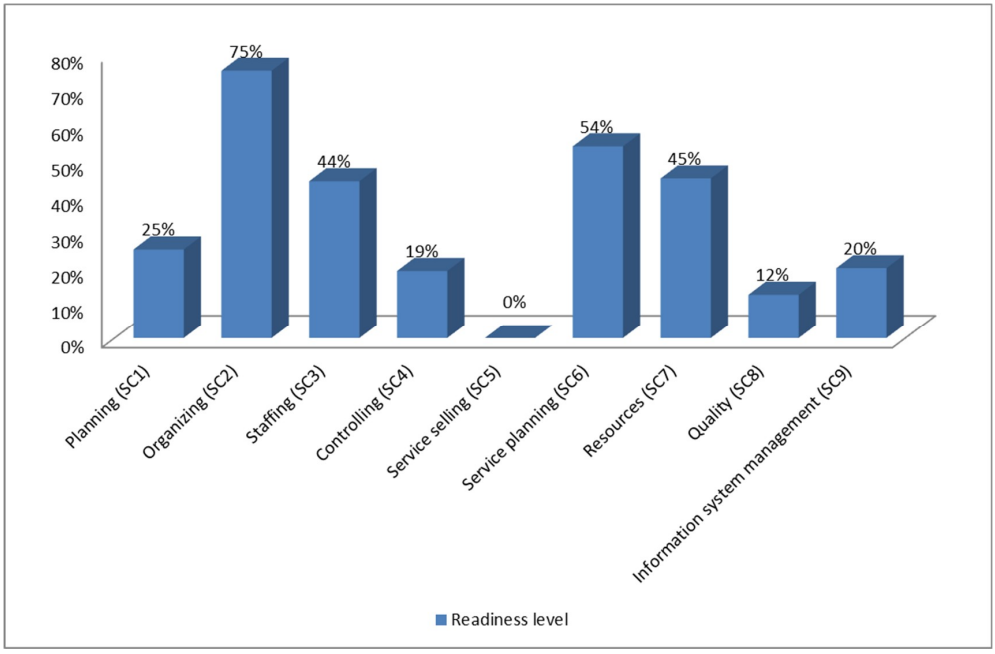

Figure 2. Subcriterion readiness level.

Based on the laboratories and subcriterion readiness level, we mapped the laboratories' readiness level using the radar chart to find out the subcriterion groups that tended to have high a readiness level. The readiness mapping is shown in Figure 3.

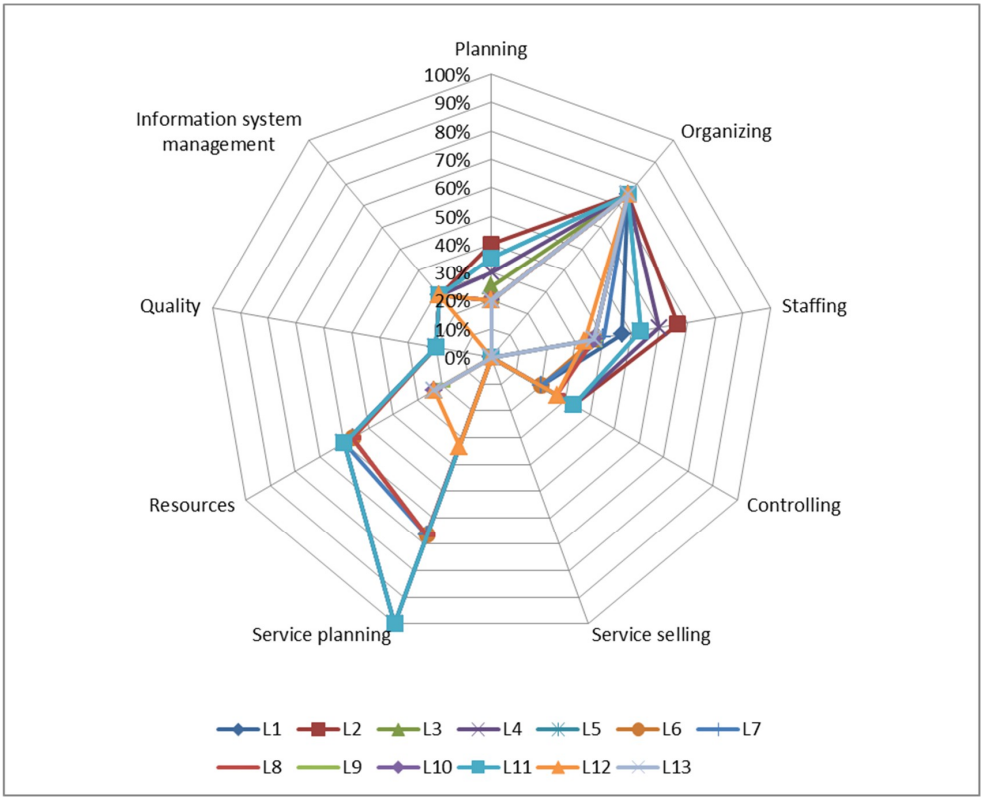

Figure 3. Radar chart of laboratories readiness mapping.

4. Discussion

A framework for assessing university laboratory readiness to be developed into testing laboratories was generated. The framework is presented in Figure 4.

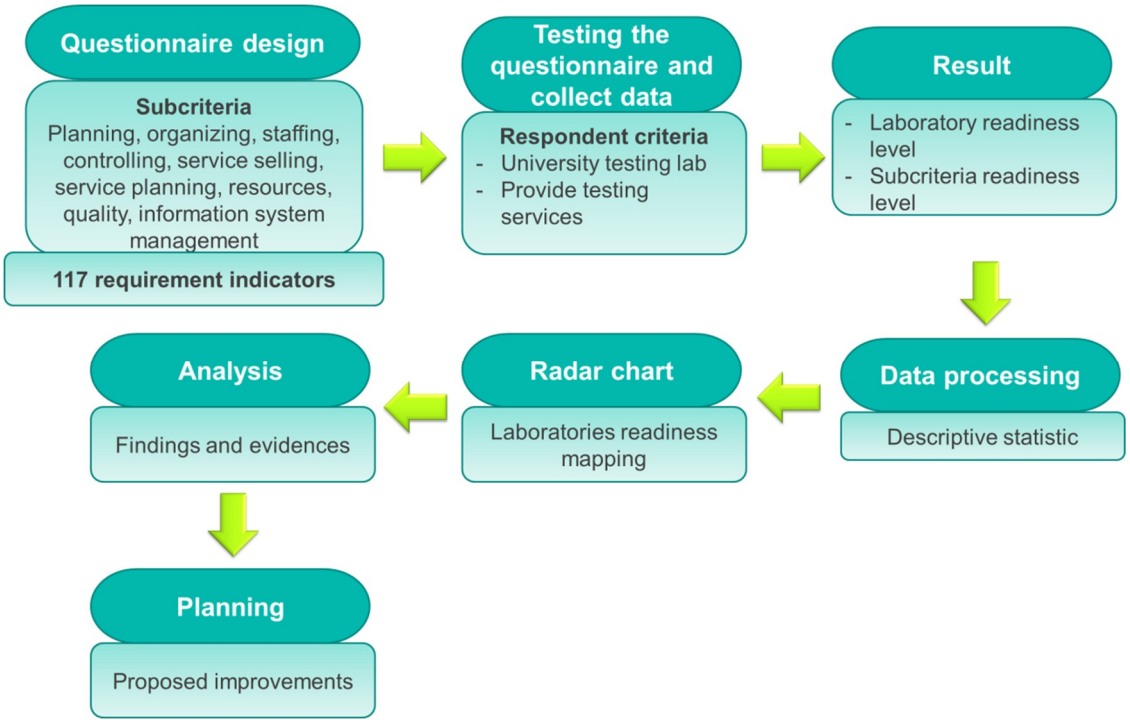

Figure 4. University testing laboratories readiness assessment framework.

The readiness level measurement of potential laboratories has been done. The subcriterion readiness level was also measured. Based on the results in Table 4, we analyzed the readiness level of the laboratories and we grouped the laboratories using a Pareto chart which is shown in Figure 5. There are four laboratories, namely L2, L4, L11, L5, which were identified as the most ready laboratories with the highest readiness level ranging above 40%. Based on the survey, the proportion of fulfillment in each subcriterion for these laboratories was higher compared to other laboratories. It is recommended for these laboratories to focus on improving the problems that cause the laboratory to be unable to carry out the existing requirement indicators. In addition, the laboratory is recommended to benchmark to an accredited laboratory in order to get representation of the ideal laboratory management system.

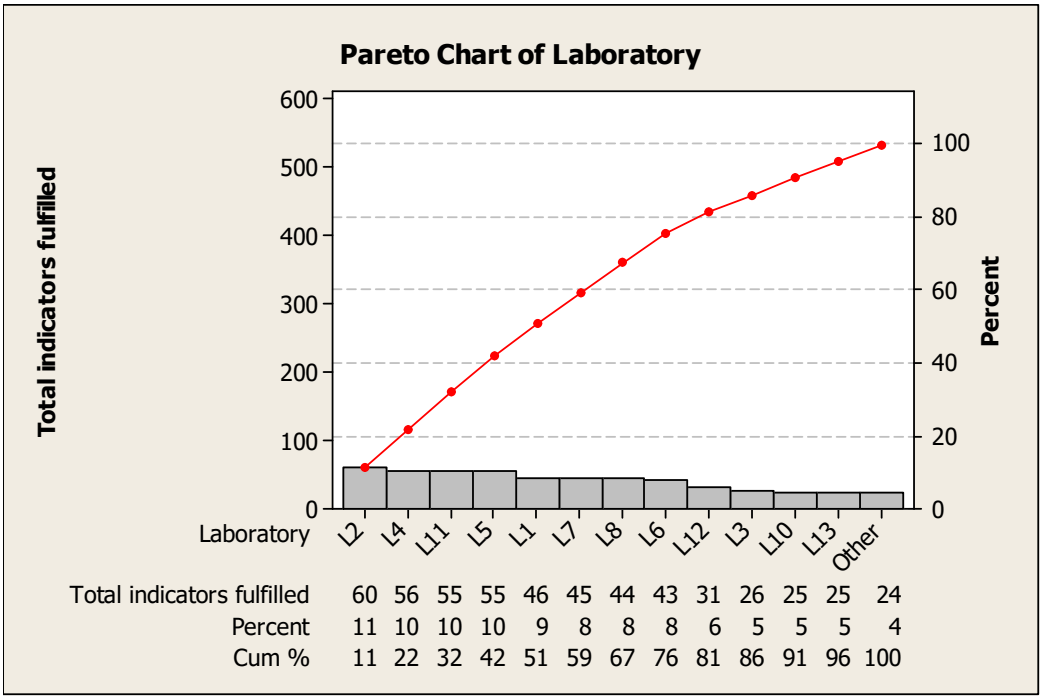

Figure 5. Pareto chart of laboratories readiness.

There are four laboratories, including L1, L7, L8, L6, identified with poor readiness level. Based on the survey, the proportion of fulfillment for SC1, SC3, SC4, SC7, SC8, SC9 in these laboratories was quite low. It is important for these laboratories to increase the understanding of personnel towards the existing requirement indicators, by inviting a standardization agency to socialize the requirements of ISO/IEC 17025. In addition, it is critical to make improvements to the problems that caused the laboratory to be unable to implement ISO/IEC 17025.

The final five laboratories, including L12, L3, L10, L13, L9, were identified as the least ready in fulfilling accreditation requirements as the proportion of fulfillment in each criterion was very low. In addition, these laboratories failed in fulfilling requirements in several subcriteria, especially SC4, SC5, SC6, and SC8, which had 0% in proportion of indicators fulfillment. This is because laboratory personnel do not understand and do not implement the requirements of ISO/IEC 17025. The initial strategy that can be done for these laboratories is to increase the level of readiness by improving the fulfillment of indicators in the mentioned subcriteria. This can be started by increasing the understanding of existing requirement indicators by laboratory personnel by conducting training and workshops for ISO/IEC 17025 and inviting standardization agencies to the events.

Shortly, the most ready laboratory, which is L2, was only capable of fulfilling 51% of the indicators and only three other laboratories (i.e., L4, L5, and L11) had equivalent levels. Meanwhile, the readiness level of nine other laboratories were lower. In addition, only the organizing subcriterion was assessed as the most ready, which is equal to 75%, while other subcriteria had a much lower level of readiness. This means that the university needs to do extra work and investment to encourage and strengthen these laboratories so that they can meet all the indicators that are required for the establishment of a testing laboratory service center.

In the case study, some improvements of the university laboratories in order to support services and commercialization of innovation product by using testing are needed based on the characteristics of licensed laboratories. The laboratory readiness was evaluated and there are several examples of evidence which act as weaknesses in each dimension of management factors. The findings are presented in Table 6.

Table 6. Existing evidence and proposed improvement.

Dimension	Readiness Level	Evidence	Proposed Improvement
Planning (SC1)	25%	Lack of organized management system	State quality management system policies and objectives Compose documents regarding quality guide, procedures, job instructions, and activity forms
		Undocumented laboratory policies, procedures, programs, and job instructions	
		Lack of quality manual	
		Unstated objective and policy regarding laboratory quality	
Organizing (SC2)	75%	Undivided responsibilities between technical and quality management	Recruit new personnel to carry out both responsibilities
Staffing (SC3)	44%	Lack of quality manager	Recruit new qualified personnel
		Lack of personnel training policy and procedure	
		No relevant documentation of personnel's competency, education, qualification, training, skill, and experience	Conduct documentation compiling training for laboratories personnel
Controlling (SC4)	19%	Lack of policy and procedure to resolve customer complaints	Conduct training for laboratories personnel on how to compile documents regarding laboratory quality management system and how to establish policies and procedures regarding test conduction
		No documentation of customer complaints, investigation, and corrective action towards them	
		No established policy and procedure to conduct corrective action	
		Lack of procedure to prevent nonconformity and policy deviation	
		Lack of audit planning and organizing	
		Lack of schedule and procedures for laboratory management review	
		Lack of periodic laboratory management review	
Service selling (SC5)	0%	Lack of customer request, tender, and contract review procedure	Formulate required procedures
Service planning (SC6)	54%	Low interest of laboratories to seek feedback through customer survey	Conduct customer satisfaction survey to improve service and management
Resources (SC7)	45%	Lack of procedure to receive, handle, protect, and identify test items	Invest in equipment and develop testing parameters especially for prioritized product produced by the university
		Lack of policy and procedure for selecting and buying services and supplies	
		Lack of procedure to purchase and receive reagents and disposable materials	
		No evaluation towards supplier was conducted	
		Lack of procedure for guaranteeing accommodation conditions and laboratory environment	
		Lack of procedure to estimate measurement uncertainty	
Quality (SC8)	12%	Lack of equipment handling and calibration procedure	Formulate calibration and intermediate check procedures and make the schedule and program
		No intermediate check was conducted	
		Lack of quality control procedure and data analysis	
Information system management (SC9)	20%	Lack of document controlling procedure, corrective and preventive action report	Formulate the required procedures and develop a management information system software to monitor the laboratory activities
		Lack of record backup making and protection procedure	

Table 6 shows the improvements that could be implemented by the laboratories. It is recommended for laboratories to create action plans by determining goals and targets for the next

period. The first stage of the plan is to improve the quality management system by focusing on problem gap improvement and fulfilling the qualifications in each dimension. During the process, monitoring and evaluation of target achievement would be needed to execute continuous improvement. The main purpose of the first stage is to actualize an appropriate management system. After fulfilling all of the qualifications, the next stage is to conduct testing by conforming to the test parameters. Related to the purpose of supporting product innovation commercialization, the laboratory has to comply with the parameters that must be tested to produce certified products. For this stage, we chose one of the technology innovations which were produced by the university, that is, the lithium battery. Based on the evaluation, it is important to improve the resource readiness by conforming the equipment and testing method to standard requirements regulated for lithium battery testing. In this case, the lithium battery must be appropriate with the three following standards:

- IEC 62660-2, Secondary lithium-ion cells for the propulsion of electric road vehicles—contains two test parameters (i.e., reliability and abuse testing)
- ISO 12405-1, Road vehicles: Electrically propelled road vehicles—contains test specification for lithium-ion battery packs and systems in high-power applications
- ISO 12405-2, Road vehicles: Electrically propelled road vehicles—contains test specification for lithium-ion battery packs and systems and high-energy application that defines tests and related requirements for battery systems

The mentioned standards above require several test parameters and machines. It is recommended to fulfill these two aspects. This could be achieved by investing in the required equipment and developing test parameters for the lithium battery.

In addition to the previously mentioned improvement strategies, it is recommended for the laboratories to form collaborative networks if the university would like to establish a testing service business center. Such a strategy would support the interorganizational relationship between laboratories in the testing service ecosystem in the university. Laboratories should cooperate with each other to share some resources and become more competitive. Resource sharing can be done by utilizing their capability in conducting different test parameters to perform tests for certain products. Some key reasons include sharing risks when entering new markets, reducing costs, and enhancing the organizational profile in selected industries or technologies.

Cooperation is a prerequisite for greater innovation, problem solving, and performance [66]. Regarding lithium battery testing, collaboration can be done by some laboratories in the university. The initial step to perform this strategy is to identify the test parameters required to conduct lithium battery testing according to mentioned standards. There are several test parameters that must be performed, including electrical measurement, measurement of cell temperature, dimension, weight, energy efficiency, and so forth. The next step is to identify test parameters that were provided by each laboratory. Then, we need to choose which laboratory will conduct which test parameter. For instance, electrical measurement is conducted by L3 and L13, dimension and weight measurement is conducted by L2, cell temperature measurement is performed by L4, and energy efficiency tests can be done by L3.

Figure 6 shows the implications provided by this study. Innovation in the technology sector can be achieved by exploiting university laboratories to conduct testing for its innovation product. To produce certified products, laboratories need to be improved using ISO/IEC 17025 and the management approach. Investment of equipment and development of testing procedures are needed to support the improvements of the quality management system, including planning, organizing, staffing, controlling, service selling, service planning, resources, and quality and information system management. Therefore, the improved laboratories would be able to provide testing of new technology and external services and the new technology commercialization could be supported. In addition, revenue generation could be supported in regard to WCU status.

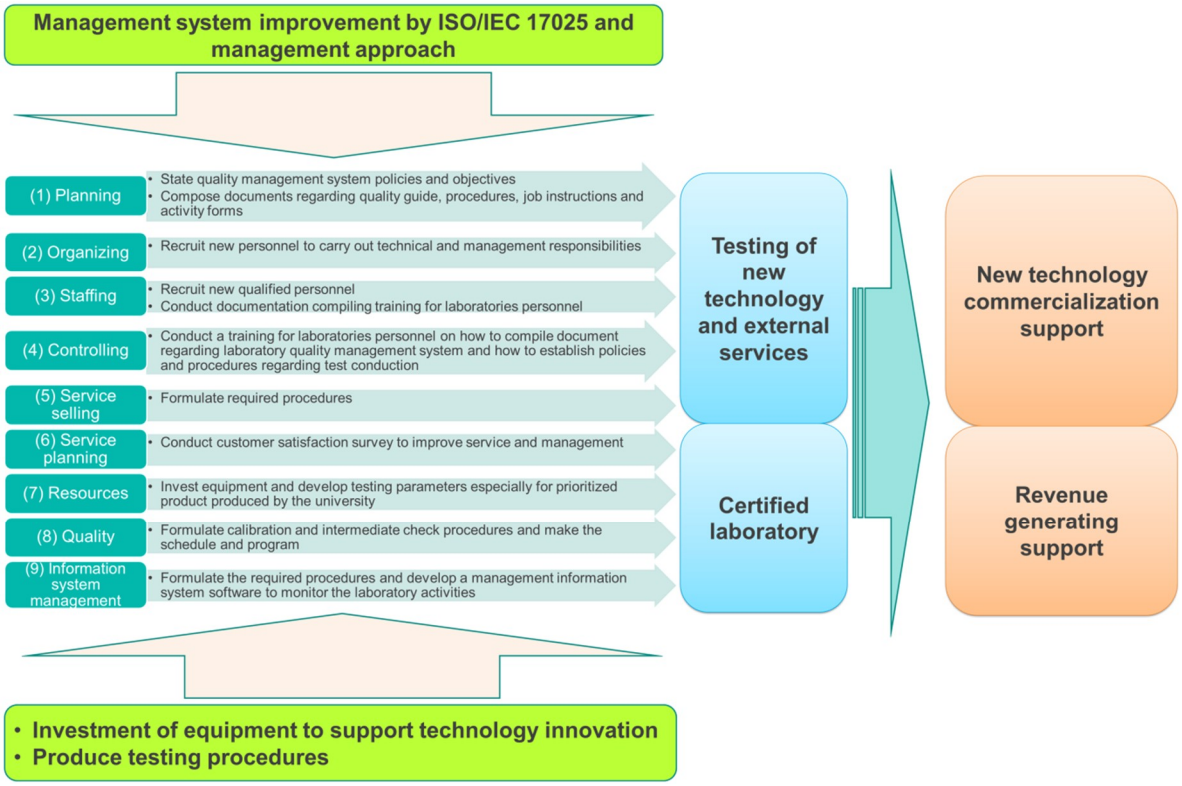

Figure 6. Summary of research implications.

The proposed framework can be used to monitor short-term and mid-term laboratory improvement to develop a certified laboratory. The measurement instrument can be used by the university body and policy-makers related to laboratory improvement to monitor the development from time to time; for instance, we can measure laboratory readiness at the beginning of the year and remeasure at the end of the year. Then, we can evaluate the gap between required conditions and existing conditions. If the gap could be minimized, we can decide to apply for accreditation. Based on the radar chart of laboratory readiness level, we can utilize the gap and propose the improvements depending on the attributes of 9 dimensions and 117 indicators.

From a management aspect, laboratories are ready to apply to be licensed testing laboratories if they have fulfilled ISO/IEC 17025 requirements. The investment of equipment that conforms to certain product testing requirements is needed to support WCU, product commercialization, and services business. For instance, the university has produced innovations of new technology for lithium batteries, electrical vehicles, and traceability. Therefore, equipment investment must be suitable for each technology product. In the case of the lithium battery product, the equipment has to comply with test parameters regulated in IEC 62660-2 and ISO 12405-1. Moreover, the university can be a certified agency after fulfilling the overall requirements. Therefore, the university would be able to assure the maximal contribution of technology commercialization and laboratory services. Future research can be done by formulating strategies to strengthen the nine dimensions in order to fulfill all of the required indicators.

5. Conclusions

This paper has developed a framework to assess university laboratory readiness to be developed as a testing laboratory to support the commercialization of new technology products resulting from the university innovation research. This research generated a measurement instrument to assess the laboratory readiness level, considering organizational audit factors in management concept and testing laboratory standard requirements. The instrument testing on 13 faculty laboratories

in the university indicated the laboratories' readiness level and organizational factors readiness. This research generated a radar chart of laboratory readiness level mapping and proposed improvements to strengthen the laboratory management system in order to accelerate towards accreditation application. Therefore, laboratories can operate as certified laboratories to provide standard services and generate certified products so the commercialization of the innovation product and revenue-generating role can be optimized.

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