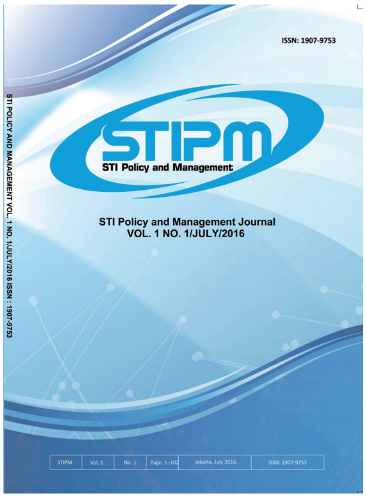

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ABSTRACT

Innovation is one of the most critical issues in research institutions which can be performed through certain routes within the technology transfer mechanism. As the demands of research implementation are increasing, a better mechanism should be deployed to foster innovation. This study will investigate the possibilities for technology transfer mechanism improvements by (i) identifying a number of steps required for innovation; (ii) measuring the efficiency of each step; and (iii) exploring the most efficient routes to innovate through the Dijkstra algorithm. Cases of research on essential oils and derivatives in the Research Center for Chemistry (RCC) of the Indonesian Institute of Sciences (LIPI) will be examined as the working example for the study. As a result of this study, a model containing a recommended sequence for the most efficient steps to innovation can be proposed. Using the proposed model, the efficiency rate of the technology transfer mechanism was increased twice, suggesting the possibility of stimulating innovation performance.

I. INTRODUCTION

Innovation is one of the most critical issues in research institutions which determine the quality of outcome to the public. The literature has consistently shown that the diffusion of innovations is a slow process with varying success (McIntosh, 2011). It occurs not only in medical research (Balas & Boren, 2000) but also across many fields, including sociology, communications, marketing, and management (Rogers, 2003).

The Indonesian government has deployed various methods and instruments to foster innovation, i.e. by issuing relevant regulations and establishing a national innovation system. In 2002 the government promulgated Law 18/2002 concerning the National System of Research, Development, and Application of Science and Technology. The provisions of Law 18/2002 have been appended with additional regulations such as Government Regulation 20/2005 on the

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transfer of technology of intellectual property and research and development results, and Government Regulation 41/2006 allowing foreign universities, research and development institutes, companies, and individuals to conduct research and development activities in Indonesia. In an attempt to support companies investing in R&D, the government issued Regulation 35/2007 which provided incentives for enterprises engaging in R&D activities, and Government Regulation 93/2010, a tax incentive policy for donations to R&D activities in Indonesia.

Despite the fact that existing methods and instruments have been provided, they have yet to enhance national economic competitiveness optimally. A study by Aiman, Aminullah and Simamora (2007) found that many barriers faced in R&D commercialization need to be overcome, especially obstacles due to weaknesses in R&D planning and marketing programs. Such R&D programs are related to the mechanisms in implementing and commercializing the research through activities of technology transfer. A study on the evolving 'state-of-the-art' in technology transfer research has also emphasized the importance of performing technology transfer effectively (Bozeman, Rimes & Youtie, 2015). Research institutions, including in Indonesia, are obligated not only to publish their findings to scientific communities, but also to implement it to societies.

Indonesia is one of the countries worldwide which has an abundance of essential oil–producing plants. It is estimated that more than 40 kinds of plant essential oils are found in Indonesia, such as oil from cloves, patchouli, lemongrass, ylang-ylang, vetiver, ginger, sandalwood, nutmeg and eucalyptus.

Essential oils are widely used in the cosmetics, food and medicines industry, and more recently developed as part of aromatherapy (Sulaswatty & Wuryaningsih, 2001). About 14 types of essential oils has been commercially cultivated in Indonesia. However, most of these essential oils cannot be used directly by industrial users because the quality could not meet the standard. If quality requirements are not met, then the value of sales would be much smaller. According to data released by the Ministry of Industry and Trade in 2007, Indonesia exported an amount of raw essential oil material abroad with a value equivalent to US$ 101.14 million, while imported essential oil products and derivatives using higher technology amounted to about US$ 381.9 million (Molide, Rusli, & Mulyadi, 2009). In 2008, exports increased to US$ 401 million while imports only slightly rose to US$ 103 million (Suhendra, 2009). These imply the increasing need in more innovation to enhance the quality and value of Indonesian essential oils (Sulaswatty, 2002).

The quality and value of Indonesian essential oils can be enhanced through the application of essential oils processing technology, such as distillation, fractionation, extraction and other purification technologies which produce separated components with higher concentrations. In addition, there are also derivative compounds as a result of a synthesized main component from other components. The obtained new compound has different characters on both characterization and function. The process for obtaining derivative compounds can be performed through chemical reactions such as oxidation, esterification, hydrogenation and others (Abimanyu. 2003).

The Research Centre for Chemistry (RCC) at the Indonesian Institute of Sciences (LIPI) has conducted research and development on essential oils since 1990s. RCC researchers have successfully developed the purification of essential oils into pure crystals, which has the potential to increase the value of Indonesian essential oil (Agustian & Sulaswatty, 2005). Some notable research developed over the years include research on essential oils such as patchouli (Agustian & Sulaswatty, 2015), citronella (Agustian, Sulaswatty, Tasrif, Laksono, & Adilina, 2007), cinnamon, vetiver, nutmeg oil, clove oil, etc. These research projects were implemented in the past through several steps of technology transfer, including by collaborating with partner from industries and universities.

The data exhibited in Table 1 shows the total number of research and development projects on essential oils in RCC LIPI since the year 2000. It is estimated that research on essential

Table 1.
List of main essential oils developed in Research Centre for Chemistry LIPI since 2000

No.	Type of essential oils	Total number of			
		Research projects	Publications*	Patents**	Cooperation projects
1.	Patchouli oil (*nilam*)	2	3	-	1
2.	Citronella oil (*sereh wangi*)	5	6	1	2
3.	Cinnamon oil (*kayu manis*)	2	3	-	1
4.	Vetiver oil (*akar wangi*)	2	3	-	2
5.	Ginger oil (*jahe*)	2	3	-	2
6.	Nutmeg oil (*pala*)	2	3	-	2
7.	Clove oil (*cengkeh*)	2	3	-	1
8.	Agarwood oil (*gaharu*)	1	-	-	1
9.	Massoia oil (*masoi*)	1	-	-	1
	Total	**19**	**26**	**1**	**10**

*) estimated number for national and international publication**) include drafted patent

Source: Database RCC LIPI, 2014

oils before 2000 number more than the above data, given the fact that at the time RCC LIPI had more researchers with relevant backgrounds who were supported by newly purchased equipment. After 2000, some researchers retired, while the others were promoted to other departments (such as the Indonesian Ministry of Research and Technology). In late 2005 LIPI began recruiting new, young researchers, with diverse education backgrounds. These newer researchers had also only been involved in essential oil development for a short time, due to the obligations of overseas higher education. Thus, practically speaking, there was not as much research on essential oil after 2000 as before 2000.

As the demands of technology transfer are increasing rapidly, better mechanisms should be deployed to enable faster implementations. Despite having been implemented, the steps required for transferring technology have not been fully studied for its performance yet. Furthermore, the existing Standard Operational Procedure (SOP) for implementing research is determined based on recurring activities which are deemed to be best practices. Therefore, this study will be important for its review of the existing technology transfer mechanism and its investigation of possibilities in increasing performance. This performance can be explored further by finding the most efficient route to innovate using the Dijkstra algorithm. The case of research on essential oils and their derivation in RCC LIPI will be examined as the working example for the study. As a result of this study, a model containing recommended sequential steps for innovation can be proposed.

II. PROBLEM FORMULATION

This section will start with a conceptual definition of the problem background, followed with a framework of the problem. Then, research questions will be determined along with the scope.

A. Conceptual definition: innovation and technology transfer

Innovation can be viewed generally as the process from idea generation to commercialization, i.e. bringing the idea or invention to the market as a new product, process or service (Mitasiunas, 2013). It passes through the phases of idea generation, research and development, product development, marketing and selling a new product or service. The idea becomes an invention when it is converted into a tangible new artifact. The inventions are a necessary seed for innovations, but the inventions do not inevitably lead to the innovation. Innovation is mostly regarded as the commercial and practical application of ideas or inventions (Trott, 2008; Varjonen, 2006). To become an innovation, an idea should pass through some steps of technology transfer. Specifically, technology transfer is designed to accelerate the diffusion of innovation (McIntosh, 2011).

The concept of technology transfer has been evolving for decades, which indicates the increasing necessities among the technology provider (university, research institute) and its user (industry, community, etc.). The traditional concept of technology transfer can be simplified as an activity to disseminate the knowledge to the public through other endeavors such as research publications in journals or proceedings, technical consultancies, research cooperation, idea exchanges in seminars and conferences, etc. However, over the last two decades, the term "technology transfer" has come to mean the formal transfer to industry which is characterized by the transfer of a property right as the result of ownership of the intellectual property generated during the conduct of research (Pereira, 2003).

A study of technology transfer processes in the United States and Germany led to the following comprehensive definition, which adopts a private-sector point of view:

> Technology transfer (is defined) as the movement of technological and technology- related organizational know-how among partners (individuals, institutions, and enterprises) in order to enhance at least one partner's knowledge and expertise and strengthen each partner's competitive position. Technology transfer occurs at all stages of the technology innovation process, from initial idea to final product. These processes integrate multiple functions, including organized research and development, design, production engineering, manufacturing, marketing, and other value-adding activities in a complex web containing multiple feedback loops. Like the innovation process proper, technology transfer is usually iterative, involving multiple transfer steps (Abramson, Encarnacao, Reid, & Schmock, 1997).

There are several ways for transferring the technology, mainly through licensing and new venturing. From the technology viewpoint, new venturing is a means to actually put a new technology into action. In other words, new ventures convey a technological invention to the commercial marketplace. This is in fact the definition of innovation: commercializing an invention (Eldering, 2006). Since 2003, technology transfer also arose as an important topic in new technology-based firms, which often need support from incubation centers (or business incubators) (Eldering, 2006b).

B. Framework and recent developments in technology transfer mechanisms

The United Nations Industrial Development Organization (UNIDO) has considered technology transfer issues in order to support sustainable industrial development (UNIDO, 2002). They have identified related issues on technology transfer, including transfer mechanisms. Specifically, they distinguished between two processes of technology transfer: vertical and horizontal processes. A vertical process occurs while transferring research into development and production, while a horizontal process refers to transferring established technology to other environments.

A framework for technology transfer has also been developed by a United Nations expert group on technology transfer. The framework comprises five key themes, i.e. (i) that technology needs assessment, (ii) an enabling environment, (iii) technology information, (iv) capacity building, and (v) the technology transfer mechanism (UNFCC, 2007).

The technology transfer mechanism aims to facilitate the support of financial, institutional and methodological activities by coordinating with involved stakeholders (UNFCC, 2007). Some of the research on technology transfer have focused on studying the mechanism of transfer, including factors and requirements, transfer stages and steps, transfer policy, etc. Table 2 shows the recent development on this research. According to the table, this study will explore the application of the Dijkstra Algorithm as a method to increase the performance of technology transfers, i.e. by selecting the most efficient route.

C. Research purpose and scope

To become an innovation, a new idea should be implemented, applied or commercialized through several steps under certain mechanism. A mechanism refers to a procedure which sorts steps of action by selecting the best route. A route may consist of one or more steps. Each step will require different allocations of human resources, equipment, cost etc. which can affect the result.

The mechanism for producing innovation can be associated with different terms, such as innovation mechanism, product development mechanism, technology transfer mechanism, etc. There is a wide range of 'mechanism' terms as innovation can take place in multiple forms and studied in various disciplines. However, in this study, the mechanism that is being referred to is a technology transfer mechanism which supports a general understanding of other terms.

The research objective of this study can be formulated as follows: "How to improve technology transfer performance by finding the most efficient route using the Dijkstra algorithm, based on the case of essential oil research in the Research Center for Chemistry, LIPI". The importance of this problem (i.e. to perform technology transfer efficiently) was highlighted

Table 2.
Framework of research development on technology transfer mechanism

Subject	Description of Research
Technology transfer steps/ stage	• Stage consists of prospecting, developing, trial and adoption based on analysis on the best technology transfer practices of a broad cross-section of government agencies, research institutions, and national and industrial laboratories (Souder, Nashar & Padmanabhan, 1990).
	• Steps including *development*, *translation*, *dissemination*, *adoption*, *implementation*, and *diffusion* according to study with broad, systematic review and consulted with technology transfer expert (McIntosh, 2011)
	• Transfer activities include funding investment, research and development, intellectual property, prototype, product, commercialization (Wang et al., 2003)
Transfer type	• Formal mechanisms (license, patent, contract) and informal mechanism (personal contact) (Bonaccorsi & Piccaluga, 1994; D'Este & Patel, 2007; Bekkers, Bodas & Freitas, 2008; Yusuf, 2008)
	• Science-based regimes (publication, patents, consultancy, spin offs) and development-based regimes (joint R&D Programs, conference participation, professional network, inflow of PhD graduates) by analyzing data from 575 valid responses of questionnaire distributed to university and industry practitioners in the Netherlands (Gilsing, Bekkers, Freitas & van der Steen, 2011).
Performance criteria/ indicator	• Human resources, institutional/ culture resources, financial resources, commercial resources (O'Shea, Allen & Chevalier, 2005; Hsu, Shen, Yuan & Chou, 2015)
	• Technological merit, business effect, technology development potential, and risk which decomposed into 18 criteria (Shen, Chang, Lin & Yu, 2010)
Measurement tools	• Econometric regression model to identify critical factors on the outcome of university knowledge transfer (Landry, Amara & Ouimet, 2007; Gonzales-Pernia, Kuechle & Pena-Legazkue, 2013; Rizzo & Ramaciotti, 2014)
	• Data Envelopment Analysis to measure the efficiency of knowledge/ technology transfer (Setiawan & Katayama, 2009; Chapple, Lockett, Siegel & Wright, 2005; Anderson, Daim & Lavoie, 2007; Ho, Liu, Lu & Huang, 2014)
	• Analytic Hierarchy Process to evaluate research readiness toward technology transfer (Setiawan, Wibowo & Haryono, 2013; Shen et al., 2010)
	• Fuzzy Delphy Method, Interpretive Structural Modelling and Analytic Network Process to determine the relative weighting of performance indicator based on the clarification of each driver's contribution to the improvement of university technology transfer (Shen et al., 2010).
	• Others (Structural Equation Modelling (Nguyen & Aoyama, 2014), hybrid recommender system (Porcel, Lorente, Martinez, & Viedma, 2012), ensemble methods for gold mining problem (Kwon, 2011), etc.)
	• Dijkstra Algorithm to find the route of technology transfer efficiently as explored in this study

by many studies on technology transfer (see for example: Nguyen & Aoyama, 2014; Thursby & Kemp, 2002; Anderson, Daim & Lavoie, 2007; Cardozo, Ardichvili & Strauss, 2011; Rowe & Temple 2011). As the technology transfer can occur through many routes, the model of technology transfer have also evolved, employing a more systematic approach (Henchion, Buckley & O'Reilly, 2006).

In order to answer the problem, this study aims to (i) identify the steps required for technology transfer; (ii) determine the performance indicator to measure the efficiency of technology transfer, (iii) using the case of essential oil in RCC LIPI, it will sort the required technology transfer steps in sequential order, (iv) Explore the most efficient route using Dijkstra Algorithm, and finally (v) recommend best practice model for technology transfer.

A technology transfer route consists of a number of steps linked sequentially. For instance, as shown in Figure 1, there are several choices of route which can be selected. The first (Route 1) will pass through Steps A-B-C-D while an alternative passes through I-J-G-H.

The selection procedure for the shortest route can refer to shortest path problem (SPP). Among several algorithms exist to compute shortest path, the two most widespread methods are based either on Dijkstra's or the Bellman–Ford algorithm (Constantinou, Stepanenko, Arvanitis, Baughan & Liu, 2008). Both algorithms work by computing some minimal spanning tree at each node that contains a consistent set of shortest paths between any pair of nodes (Constantinou et al., 2008). The Dijkstra algorithm was selected in this study due to its lower space complexity and faster running time in computation (Patel and Bagar, 2014).

The scope of this study will be limited to the development of essential oils conducted by researchers of RCC LIPI. The scope is not limited to research physically taking place in the RCC laboratory, but also research which may occur in other places as long as it has involved human resource from RCC LIPI. For example, development of essential oil from *Zingiber officinalis* and ginger root oils had been implemented to support the development of the local region in the province of West Java (Agustian et al., 2007).

The Research Center for Chemistry is an Indonesian government research institute under the Indonesian Institute of Sciences (or LIPI), which was established in 1962. The main objectives of the Research Centre for Chemistry-LIPI are to carry out research and development in the field of chemistry, disseminate the results to the public, and promote science and technology

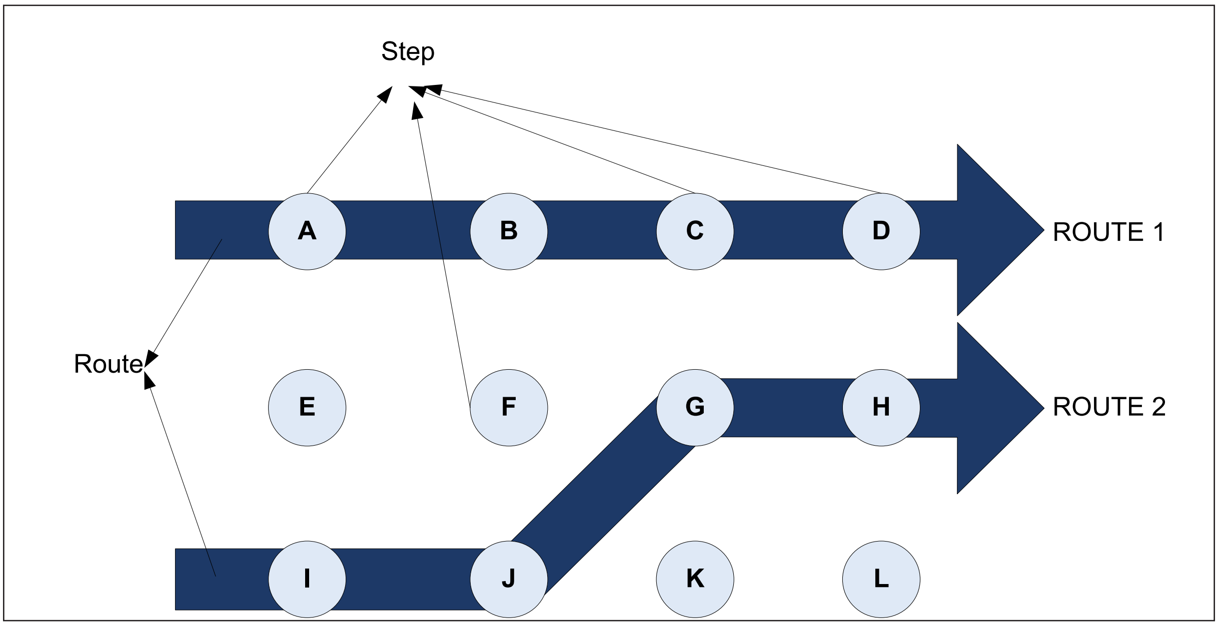
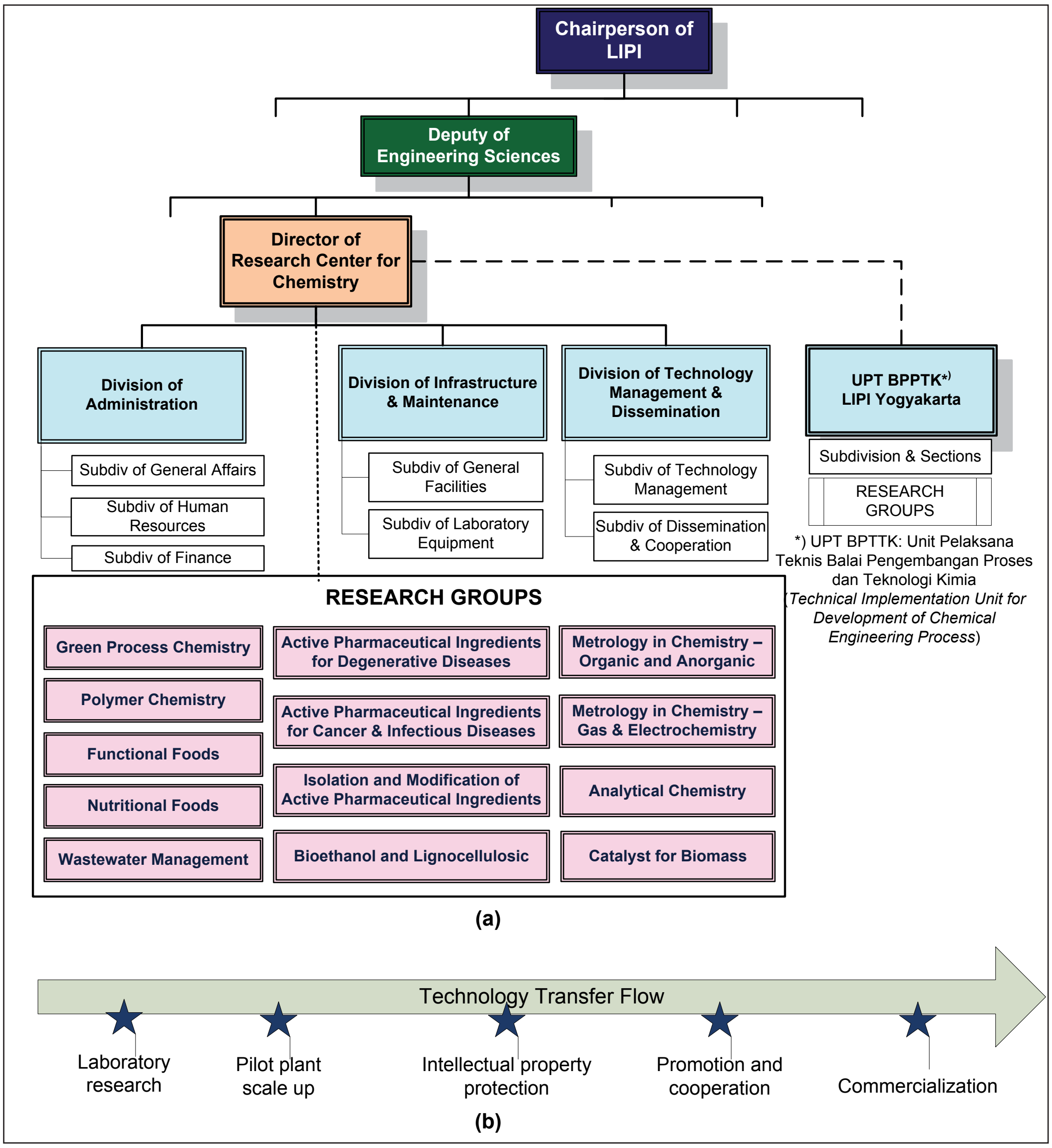


Figure 1. A number of "steps" which are linked sequentially to generate "route".



Source (a): Keputusan Kepala LIPI 3054/K/KP/VI/2014 and Surat Keputusan Kepala Pusat Penelitian Kimia LIPI No. B-223/IPT.2/KP/I/2015

Figure 2. (a) Organization structure of the Research Center for Chemistry LIPI and (b) informal flow of technology transfer

to support sustainable economic development in Indonesia.

The Research Center for Chemistry continually performs research and development through four research divisions, i.e. Analytical Chemistry and Standards, Natural Products, Food and Pharmaceuticals, Catalytic and Process Technology, and Environmental Technology. These divisions evolved into 13 research groups in 2015 to keep up with evolving industry demands through time (Figure 2). RCC also offers services and cooperation in order to promote and disseminate science and technology. The Division of Technology Management and Dissemination is responsible for conducting these services which include:

1. Cooperation in the development or readiness of chemical research
2. Chemical analysis services, data interpretation
3. Technology transfer/licensing
4. Consultation/technical assistance, student guidance
5. Proficiency testing for chemical laboratories, etc.

Figure 2 depicts the organization structure of RCC LIPI, including the informal flow of technology transfer within the organization. This flow illustrates the movement of research toward commercialization, performed by research groups and supported by each division, including the Technology Management and Dissemination division.

III. METHODOLOGY

In general, the methodology of this study was developed by integrating previous research on technology transfer mechanism framework, as well as on transfer measurement to find the shortest route. Some supporting tools will be deployed to perform the study, such as pairwise comparison and the Dijkstra algorithm.

Figure 3 depicts the proposed procedure of research, which consists of five main steps.

Step 1 (identifying steps in technology transfer to support innovation) is performed by studying related literature, exploring existing standard operating procedures (SOP) as well as observing actual practice of technology transfer in RCC LIPI to define the relevant steps required for technology transfer.

Step 2 (determining performance indicators to measure efficiency) will establish a number of indicators which can be used to measure the performance of technology transfer based on existing literature, SOP and practice.

Step 3 (case analysis of essential oil research in RCC LIPI) will deploy the case of essential oil development in RCC LIPI to support the study. This step is split into three substeps: substep 3a, determining the weight of each indicator as perceived by researchers; substep 3b, calculating the efficiency score of each step; and substep 3c, sorting the technology transfer steps in order, resulting in the emergence of some possible route alternatives.

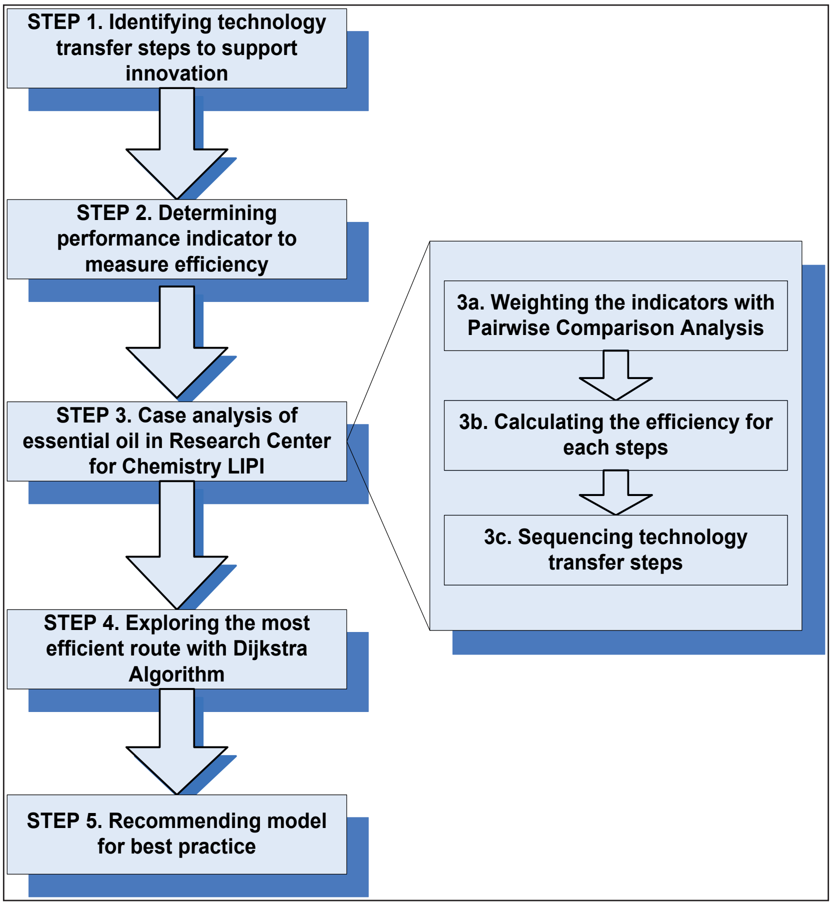


Figure 3. Research procedure for finding the most efficient route to innovate

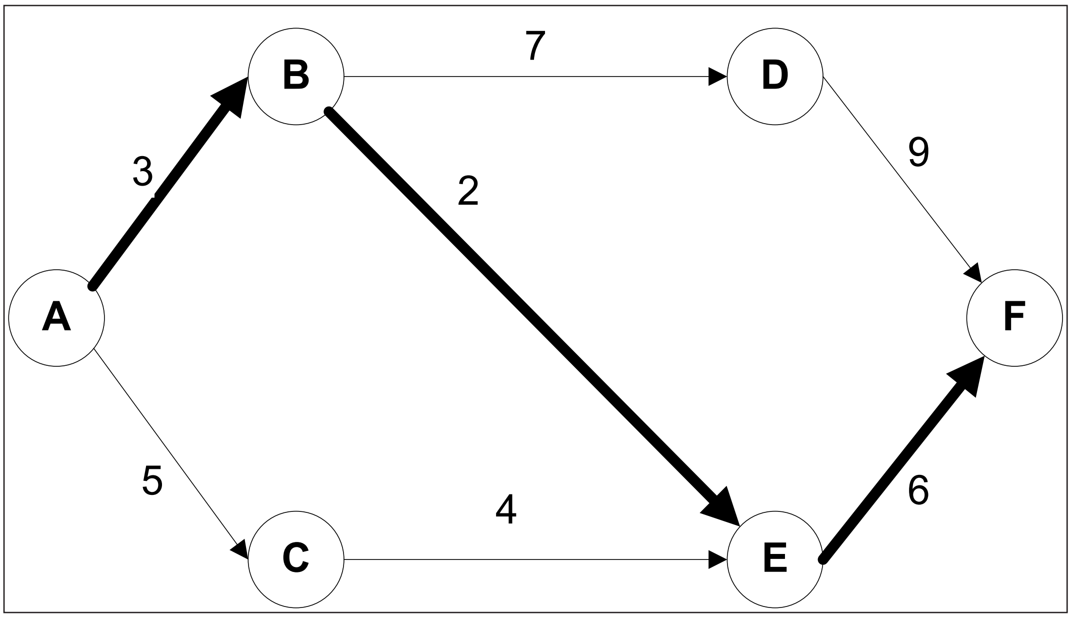


Figure 4. Illustration of finding shortest route from A to F. The weighted consecutive lines A-B-E-F show the shortest route.

Step 4 (investigating for the most efficient route with the Dijkstra algorithm) is the application of the Dijkstra algorithm iteratively to explore and select the most efficient routes based on some provided alternatives.

Step 5 (recommending model for best practice) will examine the resulting model from the application of Dijkstra algorithm and interpret it.

A. Dijkstra algorithm

The Dijkstra algorithm uses a 'greedy' approach to find the shortest route in a graph with positive weights. "Greedy" refers to an algorithm that at every step selects the best choice available at that time without regard to possible future consequences (Gass & Harris, 1996). The Dijkstra algorithm works by beginning at the starting node and repeatedly picking the next closest node of those already visited.

The algorithm has many useful applications in networking and it can be extended to a variety of problems. Some applications include finding directions between physical locations on map (e.g. MapQuest or Google Maps), solving the minimum delay path problem in networking or telecommunication, and solving problems in plant and facility layout, robotics, transportation, etc. (Nedich, 2009).

Other extended uses also include the potential application in mapping the technological landscape (Aharonson & Schilling, 2016), knowledge management (Moriconi & Snels, 2013), knowledge diffusion (Barnard, Cowan & Muller, 2012), project engineering (Liao, Egbelu, Sarker & Leu, 2011), etc.

Algorithm procedure

At each node visited, the minimum cost required to reach that node from the starting node must be considered.

1. Start at the starting node.
2. Find an unvisited node that has the least cost to reach from the visited nodes.
3. Mark that node as visited.
4. Repeat until all nodes are visited.

When reaching a node for the first time, it will be the shortest route from the start node to that node.

Figure 4 illustrates how the Dijkstra algorithm works to find the shortest route from A to F, described as follows. From A, there are two alternatives to be considered: B and C. Going to B will take the shortest distance so B will be selected. From B, there two alternatives to go: D and E. Particularly with E, in addition to A-B-E, the total distance of A-C-E should also be considered in finding the minimum distance to reach E. Among A-B-D, A-B-E and A-C-E, A-B-E has shortest accumulated distance so it will be selected. From E, there is only F remaining to be selected. However, the other route to reach F (A-B-D-F) should be also computed to confirm that A-B-E-F is the shortest route.

B. Pairwise comparison

The pairwise comparison technique is used to identify the relative importance of each objective and sub-objective. Comparisons are performed between pairs of elements within each branch of each level of the hierarchy to determine the relative value of one element as compared with another in relation to the element directly above (Fichtner, 1986).

To make a comparison, a scale of numbers is required to indicate how many times one element emerges as more important or dominant compared to another element with respect to the criterion or property their comparison is based upon. Table 3 exhibits the scale.

For example, a decision maker may need to consider, "How much more important is technology than the market in determining research readiness toward technology transfer?" The pairwise comparisons from each branch at each level of the hierarchy are entered into a matrix and used to determine a vector of priority weights. Only those elements that pertain to a common objective are compared against one another.

A set of pairwise comparison can be represented in the following matrix:

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{bmatrix} \quad (1)$$

where:

A : matrix of pairwise comparison values

w_i : weight for attribute i, $i = 1 .. n$

n : number of attributes

As the result of pairwise comparison between attribute i (w_i) compared to attribute j (w_j) can be denoted as $a_{ij} = w_i / w_j$, the above matrix A equal to:

$$\mathrm{A} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \quad (2)$$

The goal is to uncover the underlying scale of priority values w_i. In other words, given a_{ij}, find the true values of w_i and w_j.

By assuming the decision maker is consistent with respect to individual pairwise comparisons, a_{ji} is reciprocal to a_{ij} such that $a_{ij} = 1 / a_{ji}$. Hence, matrix A can be reduced to:

$$\mathrm{A} = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ 1/a_{12} & 1 & a_{23} & \cdots & a_{2n} \\ 1/a_{13} & 1/a_{23} & 1 & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & 1/a_{3n} & \cdots & 1 \end{bmatrix} \quad (3)$$

Table 3.
Relative scale of pairwise comparison matrix

Scale	Interpretation
7	Element X is strongly more important than element Y
5	Element X is moderately more important than element Y
3	Element X is slightly more important than element Y
1	Element X is equally important than element Y
1/3	Element X is slightly less important than element Y
1/5	Element X is moderately less important than element Y
1/7	Element X is strongly less important than element Y

After pairwise comparisons have been performed by the decision maker, the next step is to use this matrix to estimate the underlying scale of preferences, i.e. given a_{ij}, find the values of w_i and w_j. Due to "random" errors inherent in human judgment, it cannot be expected that the true values of w_i and w_j can be found. The user will need to be contented with good estimates of w_i and w_j (Fichtner, 1986). Several methods have been proposed to estimate weights from matrices of pairwise comparisons. One of the most common methods of deriving attribute weights is the eigenvector method.

The eigenvector method was originally proposed by Saaty (1977) and is one of the most popular methods of calculating preferences from inconsistent matrices of pairwise comparisons. When inconsistency is introduced into pairwise comparisons, more than one row or column of A is desired in order to derive a good estimate of the underlying scale of weights. The special structure of a square reciprocal matrix means that the eigenvectors can be found and the largest eigenvector can then be normalized to form a vector of relative weights (Fichtner, 1986).

Given the weighting data of paired scale, a_{ij}, which represents the comparison of scale i compared to scale j ($a_{ij}=w_i/w_j$), the task is to estimate the eigenvector of scale i and j (w_i and w_j), and eigenvalue λ_{max}. These can be determined by solving the following equations:

$$\sum_{j=1}^{n} a_{ij} w_j = \lambda_{\max} w_i \qquad (4)$$

$$\sum_{i=1}^{n} w_i = 1 \qquad (5)$$

Assume priority in $w = (w_1, \ldots, w_n)$ such as weight of stone 1 to n. A matrix of ratio comparisons can be formed and multiplied on the right to obtain nw as follows:

$$\begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_n \end{bmatrix} \qquad (6)$$

Consider n elements to be compared, $C_1 \ldots C_n$ and denote the relative 'weight' (or priority or significance) of C_i with respect to C_j by a_{ij} and form a square matrix A=(a_{ij}) of order n with the constraints that $a_{ij} = 1/a_{ji}$, for $i \neq j$, and $a_{ii} = 1$, all i. Such a matrix is said to be a reciprocal matrix. For the above example of the matrix, the value a_{ij} is represented by value of (w_i/w_j).

The weights are consistent if they are transitive, that is $a_{ik} = a_{ij} \cdot a_{jk}$ for all i, j, and k. Such a matrix might exist if a_{ij} is calculated from exactly measured data. The following step is to find the vector ω of order n such that $A\omega = \lambda\omega$. For such a matrix, ω is said to be an eigenvector (of order n) and λ is an eigenvalue. For a consistent matrix, $\lambda = n$.

For matrices involving human judgement, the condition $a_{ik} = a_{ij} \cdot a_{jk}$ does not hold as human judgements are inconsistent to a greater or lesser degree. In such a case, the ω vector satisfies the equation $A\omega = \lambda_{max}\, \omega$ and $\lambda_{max} \geq n$. The difference, if any, between λ_{max} and n is an indication of the inconsistency of the judgements. If $\lambda_{max} = n$ then the judgements have turned out to be consistent. Finally, a consistency index can be calculated from $(\lambda_{max-n})/(n\text{-}1)$. That needs to be assessed against judgments made completely at random. Saaty, for instance, has calculated large samples of random matrices of increasing order and the consistency indices of those matrices (Saaty and Vargas, 2001). He randomly generated reciprocal matrix using scale, 1/9, 1/8, 1 , …, 8, 9 and

Table 4.
Consistency index value for some matrix size n

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Source: Saaty (1977)

retrieved the random consistency index to see if it is about 10% or less. The average random consistency index of sample size *n* matrices is shown in Table 4.

A true consistency ratio (CR) is calculated by dividing the consistency index for the set of judgments by the Index for the corresponding random matrix. Saaty suggests that if that ratio exceeds 0.1 the set of judgments may be too inconsistent to be reliable. In practice, CRs of more than 0.1 sometimes have to be accepted. A CR of 0 means that the judgements are perfectly consistent.

C. Efficiency measurement

Efficiency refers to the ability to produce the desired result with the least resource or effort and minimal waste. As a measurable concept, efficiency is quantitatively determined by the ratio of useful output to total input (Daraio & Simar, 2007). In this study, the indicators for measuring the efficiency of technology transfer step have been determined as follows.

Input Indicators

- Cost

Cost covers the general expenditure required to purchase, assign or allocate material, human resources, equipment, maintenance, etc. in each step of the technology transfer.

- Time

Time can be regarded as a "resource" which reflects the period or duration required to complete each step. It is included as a separate indicator since time is difficult to be equated with money.

- Risk

Risk indicates the potential of losing value due to the failure of a related step. It is a consequence of action taken in spite of uncertainty. Risk is classified as an input indicator as risk needs to be minimized to perform the step successfully. Hence, it can also be treated as a "resource".

Output indicators

- Benefit

Benefit is an advantageous result obtained as compensation for performing a certain step. It is usually represented in monetary value such as profit or royalty, though it is also available in the form of intangible things such as convenience, payment relief, etc.

Efficiency for each step of technology transfer can be formulated below.

$$E = \frac{Output}{Input} = \frac{B}{(C+T+R)} \quad (7)$$

where E: Efficiency, B: Benefit, C: Cost, T: Time, R: Risk.

Ideal efficiency (Ei) can be defined as efficiency of each step at ideal condition. This ideal condition can be achieved when output value set at maximum (benefit = 5) and input set at minimum (cost, time and risk = 1 respectively).

$$Ei = \frac{Max\,Output}{Min\,Input} = \frac{B_{max}}{(C_{min} + T_{min} + R_{min})} \quad (8)$$

where, E: Efficiency, B:Benefit, C: Cost, T: Time, R: Risk

The efficiency ratio (Er) then can be derived through a comparison between actual efficiency (E) to ideal efficiency (Ei):

$$Er = \frac{E}{Ei} \quad (9)$$

The Dijkstra algorithm works by selecting the least minimum score of each route, where a lesser score means a better result. However, the opposite applies to the efficiency score, i.e. a higher efficiency means a better result. In order to comply with the algorithm, this ratio must be converted by introducing new terminology such as the inefficiency ratio (Ir), which is defined as:

$$Ir = 1 - Er \quad (10)$$

The lower the score of inefficiency, the better the value of result obtained. By using Ir, the algorithm will search for the least Ir to find the minimum score of inefficiency (and conversely, find the maximum score of efficiency).

IV. RESULT AND DISCUSSION

This section is organized thusly: first, it describes the result and then discusses it according to each research procedure as prescribed in previous section.

A. Step 1: Identifying technology transfer steps to support innovation

Technology transfer involves several stages such as prospecting, developing, trial and adoption (Souder, Nashar & Padmanabhan, 1990). Each stage consists of a number of steps. In the initial step, one of the important factors that determine the success of the transfer of technology is the selection and evaluation of appropriate research that is ready to be implemented. This selected appropriate research will affect the overall performance of technology transfer. The readiness of the research to be implemented should be evaluated by its technical feasibility, economic feasibility, market potency, user interest, etc.

A number of studies have been performed to investigate the steps required for technology transfer. Souder has proposed four stages of technology transfer: (i) prospecting; (ii) developing; (iii) trial; and (iv) adoption (Souder et al., 1990). He identified the stakeholders involved in each stage such as the developer, disseminator, sponsor, implementer, etc.

In the context of food industries, Donnelly (2000) presented a model for innovation management in public research. This model illustrated the move from information generation in precommercial development into commercialization, which has included the more specific steps required for technology transfer (Figure 5).

Meanwhile, Katayama (2007) has presented a set of knowledge and skills, including indicators and measurement tools, that are required in technology transfer in an intergenerational context. He recommended four main managerial techniques to perform these flows: (i) management techniques for research and development; (ii)

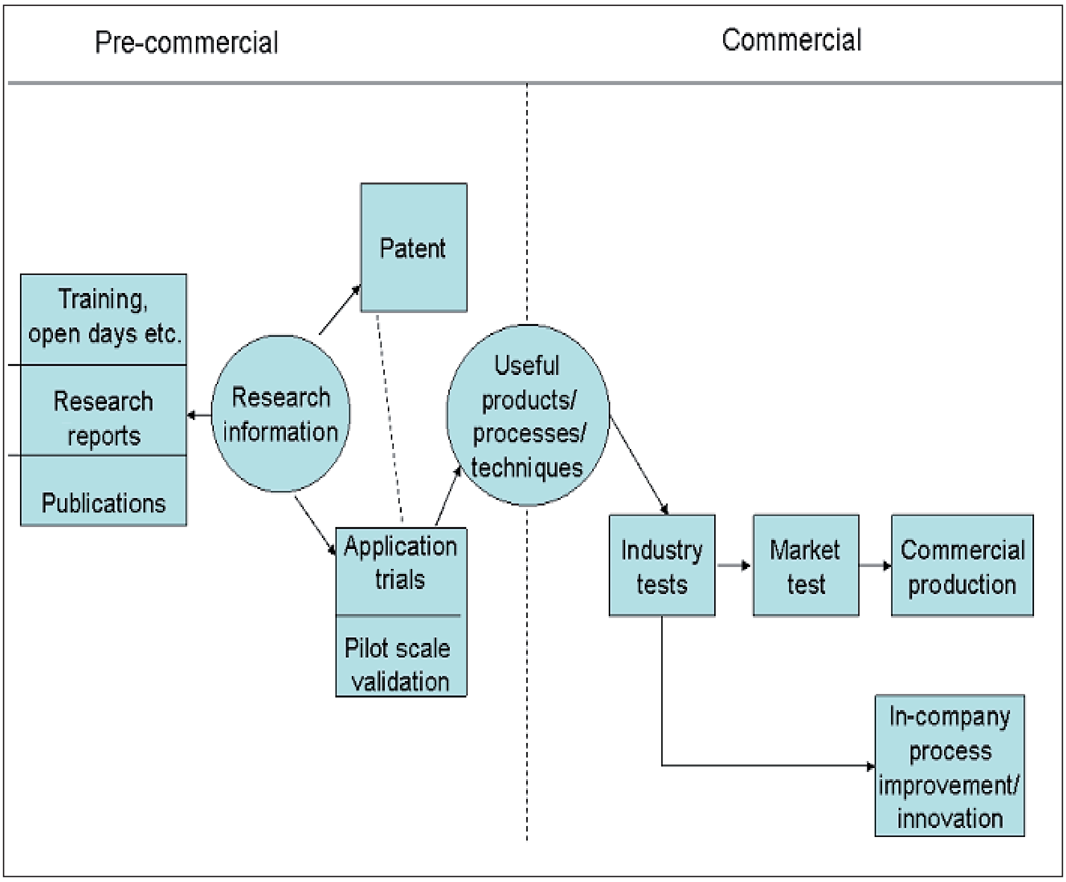


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Figure 5. Model for innovation management in public research (Donelly, 2000)

production management techniques; (iii) logistic (supply and delivery) management techniques; and (iv) environmental management techniques. These techniques have been implemented to measure the efficiency of knowledge and technology transfer (Setiawan & Katayama, 2009) and to evaluate research readiness for technology transfer (Setiawan, Wibowo & Haryono, 2013).

The Research Center for Chemistry LIPI has developed standard operating procedures (SOP) supporting technology transfer (Pusat Penelitian Kimia-LIPI, 2014). Although the term "technology transfer" itself was not stated explicitly in the procedures, the activities within technology transfer have been generally covered in various forms, such as in cooperation procedures, chemical analysis administration procedures, customer service procedures, intellectual property management procedures, risk control procedures, etc.

In addition, assessment tools have been also developed in RCC LIPI, namely F-PATH (*Form Persiapan Alih Teknologi Hasil Litbang* or Assessment Form for Technology Transfer Preparation) (Setiawan, Priyanto & Haryono, 2012). This form was developed based on the above study and conforms to the Technology Readiness Level classification system, i.e. a tool utilized by the Ministry of Research to assess research readiness for commercialization. The Technology Readiness Level system in Indonesia was adopted by the Agency for the Assessment and Application of Technology (BPPT, *Badan Pengkajian dan Penerapan Teknologi*) from the National Aeronautics and Space Administrations (NASA) of United States of America. In F-PATH, five main characteristics of research are assessed: (i) product/technology eminence; (ii) market and promotion; (iii) production and supply chain; (iv) human resource competency; and (v) financial and economic feasibility.

F-PATH contains more specific steps required for technology transfer and will be used as main framework in this study. In addition to other related literature, the steps used as the framework of this study consist of the following items:

1. Market research

Market research is an organized effort to identify the targeted niche of the developed product. It can be performed by analyzing current applications of similar products, interviewing respondents, comparing to competitors, etc.

2. Literature review

A literature review is intended to obtain as much information as possible (particularly scientific information) regarding research and development mechanisms for the product. Sources of information can include journals, proceedings, books, electronic media, patent databases, etc.

3. Obtaining financial support

Financial support is important in order to carry out research and development of the product. Obtaining financial support may consist of finding or receiving requests from financial providers, applying research proposals, attending selection processes, signing agreements and so on. Financial providers can come from domestic or international institutions, and public or private sectors such as government, university and industry. The time required to obtain financial support may vary too, depending on the provider and the starting point of research. Different providers will require different mechanisms, terms and conditions. Research started from scratch or new ideas can take longer to convince the funder compared to continued research.

4. Preparing resources (manpower, material purchasing, equipment setup, etc.)

This step involves activities such as assigning human resources, purchasing materials/equipment, setting up equipment, preparing operation procedure, etc. Among these activities, purchasing material/equipment seems to take the longest time (e.g. up to 6 months), as it mainly depends on delivery time as well as standardized procurement procedures implemented by the government. In certain cases, chemical materials and equipment are not available in the warehouse of the distributor or domestic manufacturer, hence only obtainable by importing from overseas.

5. Research and development (R&D) activities (in laboratory or field study)

This step mainly relies on the capability and competency of the researchers, supported with reliable equipment, in performing research and developing the product. The activities in this step vary upon the product that is going to be developed.

6. Simulation

Simulation is usually used when the real system cannot be engaged, whether it may be inaccessible, dangerous, currently only in the design phase, or whether it may simply not exist. Simulation can be performed by imitating the operation of a real-world process or system over time. A model may need to be developed first to represent the key characteristics or behaviors and functions of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time.

7. Scientific publication

The results of research often need to be published as a form of the researchers' responsibility toward scientific communities. This step may become important to ensure that product development has been conducted in an appropriate and reliable manner.

8. Registering intellectual property rights (patent, industrial design, etc.)

This step is very important for protecting the results of the research and its commercialization in the future. At the Indonesian Institute of Sciences, this activity is coordinated mainly by the Center for Innovation. Researcher only need to send the application form and supporting documents for their invention to the center.

9. Production analysis and design

Production analysis and design refers to the planning and designing of the production process, specifically manufacture of the developed product. Activities involved include determining the production process, scheduling operations, identifying required equipment and facilities, designing plant space and layout, planning selection of supply chain elements (supplier, distributor, wholesaler, etc.), setting standard operating procedures, constructing maintenance mechanisms, and so on.

10. Feasibility study

A feasibility study measures the readiness of the research to be commercialized, judged from the perspective of the economic value of the manufactured product. This step is crucial in convincing investors to provide adequate funding for the manufacture of the product. Feasible results of the study are often included in business plans that are delivered to the investor.

11. Production upscaling

Scaling up refers to the conduct of research and development at a larger scale. It usually serves as a bridge from laboratory-scale to industrial-scale. A number of parameters obtained from the laboratory scale often need to be adjusted to support larger production numbers. By upscaling, it is expected that the designed production process can be conducted with increasing accuracy while maintaining quality at an industrial scale.

12. Prototyping and market testing

Prototypes are often required to help test the market. Prototypes can also be attached in the business plan to help in convincing investors.

13. Promotion or dissemination

Promotion or dissemination of research results aims to find suitable customers and investors. Activities may involve exhibition, customer visits, website or electronic media promotion, etc.

14. Collaboration (with university, research institute, industry, etc.)

Collaboration can be any activity involving partners in research and development. It may include research on different aspects of the product, product analysis, production testing, market testing, etc. Time required can be shortened by collaborating since R&D activities can be performed concurrently with partners.

15. Technology transfer to user

This step is required as the implementation of "innovation". The term "user" in this context refers to partners who have been acknowledged through official agreement. The activity involves both tangible and intangible transfers of knowledge and technology through technical assistance, consultancy, training, etc.

16. Obtaining user feedback

Obtaining user feedback is important in order to improve the research. This can be performed by visiting users directly or contacting them via telecommunication media.

B. Step 2: Determining performance indicator to measure efficiency

Table 5 exhibits the scores of performance indicators as perceived by respondents. These values are in the following scale: 1 = very low, 2 = low, 3 = average, 4 = large, 5 = very large. For example, the first step, conducting market research, was perceived by respondents to have on average a large benefit (with a score of almost 4), average risk (score = 3), an average time demand (score = 3.3) and a considerably large cost (score = 3.5).

In terms of cost, research and development activities (in the laboratory or field) is perceived to have the highest cost. Surprisingly, this step has also been perceived to take the longest time with the highest risk. This result may be reasonable since the respondents are involved frequently in research and development activities.

However in terms of benefit, respondents thought that scientific publications had contributed the highest benefit to technology transfer steps for innovation. This is also supported by the other finding that publishing papers and reports is the key channel through which university research impacts industrial R&D (Cohen, Nelson & Walsh, 2002).

Among technology transfer steps, obtaining user feedback was perceived relatively low in all four indicators. Feedback from users is often needed after the developed technology is ready, i.e. to set up machines, adjust processes, etc. Therefore, respondents gave it low scores.

C. Step 3: Case analysis of essential oil research in Research Center for Chemistry LIPI

Over thirty research projects have been conducted in RCC LIPI on various types of essential oil products, including derivatives. Some examples of essential oil products developed are patchouli oil, citronella oil, cinnamon oil, vetiver oil, ginger oil, nutmeg oil, and clove oil. Each type may be researched more than once for different aims and purposes. For example, research on citronella oil could be developed in three directions: (i) to enhance its extraction technology process; (ii) to determine its potential application; and (iii) to scale up the production process. These research projects were developed by teams consisting

Table 5.
Average indicator score for each step of technology transfer

Code	Step	Average score for indicator			
		Cost	Time	Risk	Benefit
A	Market research	3.5	3.3	3	3.8
B	Literature review	4	3.9	2.6	4.3
C	Obtaining financial support	3	3.2	3.7	4
D	Preparing resources (manpower, material purchasing, equipment set up, etc.)	3.1	3.4	3.3	3.7
E	Research and development activities (in laboratory or field study)	4.9	4.3	3.9	4.6
F	Simulation	3	3.3	2.3	2.7
G	Scientific publication	4.2	3.2	2.6	4.8
H	Registering Intellectual Property Right (Patent, Industrial Design, etc.)	3.5	3.5	2	3.2
I	Production analysis and design	3.5	3.5	2.3	3.3
J	Feasibility study	3.5	3.3	2.7	3.7
K	Production upscaling	4.4	4	3.9	4.4
L	Prototype and or market testing	3.3	3.5	3	3.3
M	Promotion or dissemination (training, exhibition, etc.)	3.4	3.3	2.6	3.1
N	Collaboration (with university, research institute, industry, etc.)	4.3	4	3.3	4.4
O	Technology transfer to user	3.5	3.5	2.3	2.3
P	Obtaining user feedback	2.2	2.3	2.2	2.2

Table 6.
Normalized weight of each indicator as perceived by respondent

Respondent ID	Weight of indicator				CR
	Cost	Time	Risk	Benefit	
Researcher 1	0.61	0.26	0.07	0.06	0.14
Researcher 2	0.11	0.40	0.40	0.09	0.19
Researcher 3	0.43	0.36	0.15	0.07	0.32
Researcher 4	0.11	0.18	0.28	0.43	0.33
Researcher 5	0.55	0.24	0.15	0.05	0.18
Researcher 6	0.55	0.26	0.12	0.07	0.21
Researcher 7	0.48	0.25	0.07	0.21	0.26
Average	0.41	0.28	0.18	0.13	0.23

of one principal researcher, several assisting researchers and supporting staff (e.g. analyst, technical and administration staff).

In this study, only researchers who were involved frequently in essential oil development were selected. Among eight researchers suiting the criteria, only seven were available for assessment. They were asked to fill in the questionnaire to assess their preferences of technology transfer routes. The questionnaire was then analyzed and verified for the answer.

a. Step 3a: Weighting the performance indicator with pairwise comparison

Each respondent was asked regarding their preference of indicator importance, and their answers were compared to each other. The answer then normalized by pairwise comparison to obtain the eigenvector weight.

Table 6 shows that on average, respondents perceived that the most important factor for measuring the efficiency of each technology transfer step is cost, followed consecutively by time, risk and benefit. The consistency ratio for the perception of these indicator comparisons on average is 0.23, which demonstrates that the judgement made by respondents is 77% consistent. Saaty suggested that the ideal CR should be above 90%; however, a CR below this value can also be accepted until some degree with reasonable reason (Saaty & Vargas, 2001). A lower CR score shows that some respondents may be confused in deciding which factors are more important in measuring the efficiency of steps. Some respondents with high CR (e.g. more than 0.3 for practice purpose) have been requested to reconsider their preferences. As result, they have resubmitted their preferences. These preferences were then normalized using the eigenvector value to obtain the ideal – almost fully consistent – weighted score of the indicators.

b. Step 3b: Calculating efficiency for each step

After the weighted score was obtained, the next process was to calculate the efficiency score for each step. Using the defined formulas (7), (8) and (9), the efficiency ratio (*Er*) score for each step has been summarized in Table 7.

On average, respondents perceived that the most efficient step for technology transfer occurred in market research. This is supported by the fact that market research conducted by researchers is usually based on desk study, interviewing industrial partner and – in some cases – visiting customers. These activities do not require large resources and have little risk compared to the size of benefit obtained.

The next most efficient step is registering intellectual property rights, followed closely by preparing resources and literature review. These steps were also considered as having low risk, cost and time with large benefits (Table 5).

Research and development activities, along with production upscaling, were viewed as the least efficient steps by respondents. According to Table 5, despite having large benefits, the cost for performing both of steps were also large (or higher, as in the case of R&D). These are also in line with their perspective that the risks for these activities were high, hence reducing the step efficiency.

Table 7.
Efficiency ratio score for each technology transfer steps

Code	Step	Efficiency ratio (%) for respondent no.							Average
		1	2	3	4	5	6	7	
A	Market research	27.31	13.16	46.99		22.32	20.68	22.21	25.44
B	Literature review	13.41	16.31	10.67	34.83	8.34	6.76	21.73	16.01
C	Obtaining financial support	10.67	4.00			8.00	8.00	25.00	11.13
D	Preparing resources (manpower, material purchase, equipment setup, etc.)	16.77		31.16	10.67	11.09	3.00	23.55	16.04
E	Research and development activities (in laboratory or field study)	15.40	3.51	5.53			3.48	20.34	9.65
F	Simulation	12.29	10.46	16.00		8.00	4.14	20.43	11.89
G	Scientific publication	20.64	16.31	15.28	5.00			22.21	15.89
H	Registering intellectual property right (patents, industrial design, etc.)	28.95	6.52	18.20		16.00	5.54	23.19	16.40
I	Production analysis and design	20.38	8.58	21.69		4.00	6.93	20.00	13.60
J	Feasibility study	15.55	8.58	21.69		4.27	8.00	20.00	13.01
K	Production upscaling			10.42	5.18	6.70	4.00	20.43	9.34
L	Prototype and/or market testing	14.49		18.20		9.29	3.52	28.79	14.86
M	Promotion or dissemination (training, exhibition, etc.)	8.23	11.12	12.46	23.27	4.00	8.00	20.00	12.44
N	Collaboration (with university, research institute, industry, etc.)	10.65	4.39	9.46	21.94		7.17	25.00	13.10
O	Technology transfer to user	5.01	3.88	16.00		4.00	6.42	30.00	10.89
P	Obtaining user feedback	11.21	6.56	16.00		8.00	12.00	20.00	12.29
	Average	15.40	8.72	17.98	16.82	8.77	7.18	22.68	13.93

c. Step 3c: Sequencing technology transfer steps

The sequencing of technology transfer steps as preferred by each respondent are exhibited in Table 8. For example in this table, market research was perceived by Respondents 3, 5 and 6 to be an appropriate second step of technology transfer; Respondent 7 thought that it should be conducted in the eleventh step. All respondents thought that literature reviews should be performed first in the technology transfer process.

From the average score of each step, the sequential order of technology transfer step has been listed in Table 9. Steps with similar or close values reflect that one or more among them may be performed concurrently.

Figure 6 shows the initial estimation of the sequence of technology transfer steps based on average sequential score. However, the correlation flow between two steps cannot yet be determined, e.g. which step is predecessor and which one is successor. To do so, we need to analyze the number of selected flows by each respondent as represented in Table 10.

The data in Table 10 represents the number of respondents who select two consecutive steps originating in the first column to a destination in the next column. For example, from Step A, there are several alternatives to be selected as successor steps: two respondents selected C, one D, one E and one F. Step C should be considered first for the next successor of Step B without denying other alternatives. It is continued from Step C with a similar procedure as the previous step for selecting the next step.

As identified in Table 9, the starting point of technology transfer is B (literature review). From Step B, there are several alternatives to be

Table 8.
Step sequence as perceived by respondents

Code	Steps	Step sequence for respondent no.							
		1	2	3	4	5	6	7	Average
A	Market research		3	2		2	2	11	4.0
B	Literature review	1	1	1	1	1	1	1	1.0
C	Obtaining financial support	3	4	3	2		4	2	3.0
D	Preparing resources (manpower, material purchasing, equipment set up, etc.)	2	2	4	3	5	3	4	3.3
E	Research and development activities (in laboratory or field study)	4	5	5	4	3	6	3	4.3
F	Simulation	6	7			6	8	12	7.8
G	Scientific publication	10	6	7	5		7	7	7.0
H	Registering intellectual property rights (patents, industrial design, etc.)	5	13	6	6	4	5	10	7.0
I	Production analysis and design	7	11	7		8	11	6	8.3
J	Feasibility study	9	10	8		10	10	13	10.0
K	Scaling up production		8	9		7	15	14	10.6
L	Prototype and or market testing	8	12	10		9	9	8	9.3
M	Promotion or dissemination (training, exhibition, etc.)		16				13	16	15.0
N	Collaboration (with university, research institute, industry, etc.)	11	9	11	7		12	5	9.2
O	Technology transfer to user		15				16	15	15.3
P	Obtaining user feedback	12	14	12			14	9	12.2

Table 9.
Sequential steps as sorted by respondents

No.	Code	Sequential Steps	Sequential Score
1	B	Literature review	1.0
2	C	Obtaining financial support	3.0
3	D	Preparing resources (manpower, material purchasing, equipment set up, etc.)	3.3
4	A	Market research	4.0
5	E	Research and development activities (in laboratory or field study)	4.3
6	G	Scientific publication	7.0
7	H	Registering Intellectual Property Right (Patent, Industrial Design, etc.)	7.0
8	F	Simulation	7.8
9	I	Production analysis and design	8.3
10	N	Collaboration (with university, research institute, industry, etc.)	9.2
11	L	Prototype and or market testing	9.3
12	J	Feasibility study	10.0
13	K	Production upscaling	10.6
14	P	Obtaining user feedback	12.2
15	M	Promotion or dissemination (training, exhibition, etc.)	15.0
16	O	Technology transfer to user	15.3

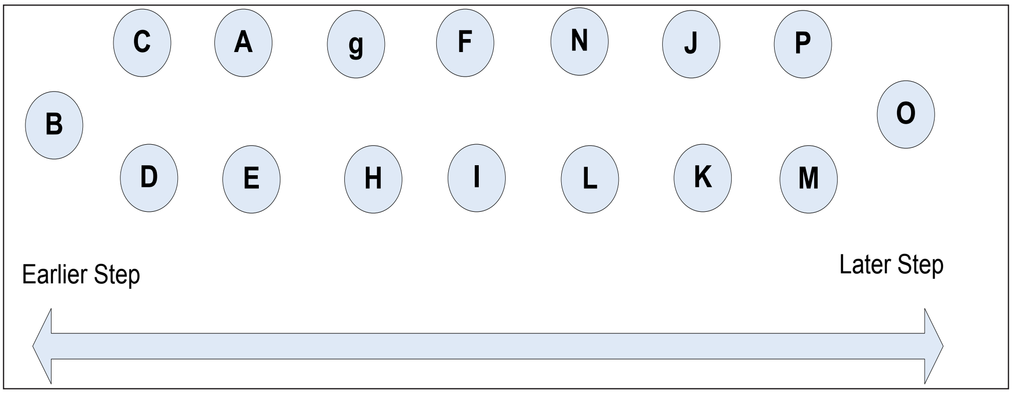

Figure 6. Initial prediction for sequential location of technology transfer step

Table 10.
Number of selected flow between two steps

To / From	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	Number of Flow for Adjacent Steps															
A			2	1	1	1										
B	3		2	2												
C				2	3			1								
D	1		2		2	1								1		
E				1			3	3								
F									1	1	2	1				
G						2		1				1		1		
H	1			1	1	1			1					1		1
I							1			1		3		1		
J							1		2		2					
K									1			1		1	2	
L								1		3				1		1
M																1
N									1	1			1			2
O													2			
P								1			1				1	

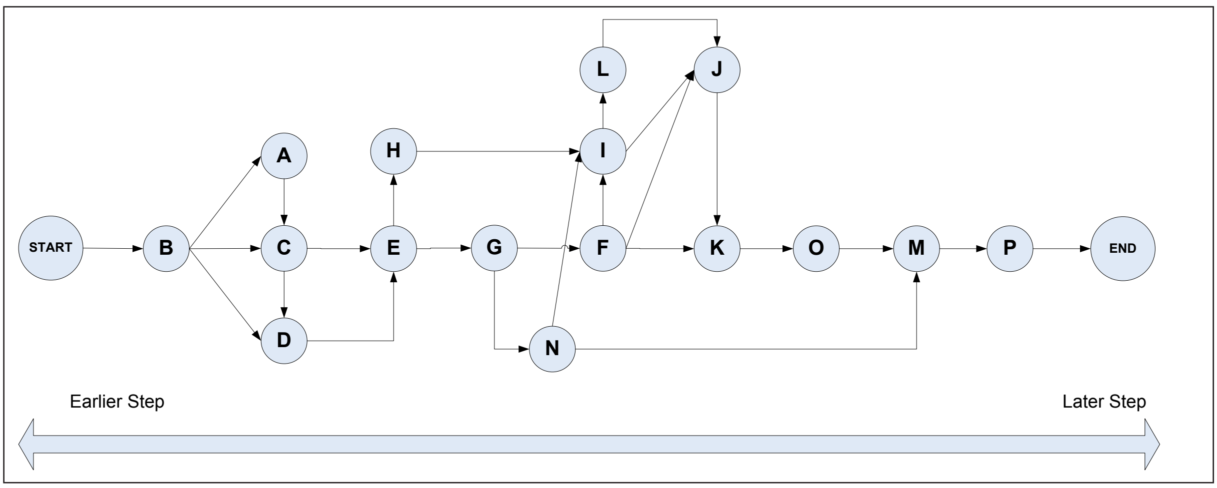

Figure 7. Step sequence with flow

selected as successor steps: three respondents selected A, two C and two D. Step A would be considered first without neglecting other alternatives. In the case of reciprocal flow – as some respondents selected A to B and B to A – flow is determined by calculating which flow had more respondents, deducted by the smaller one. Additional policies may be implemented to accommodate certain circumstances. For instance, if the inefficiency ratio between two steps is too high while the number of respondent is small, it can be ignored. By following this procedure and policy, the flow of whole steps can be constructed as in Figure 7.

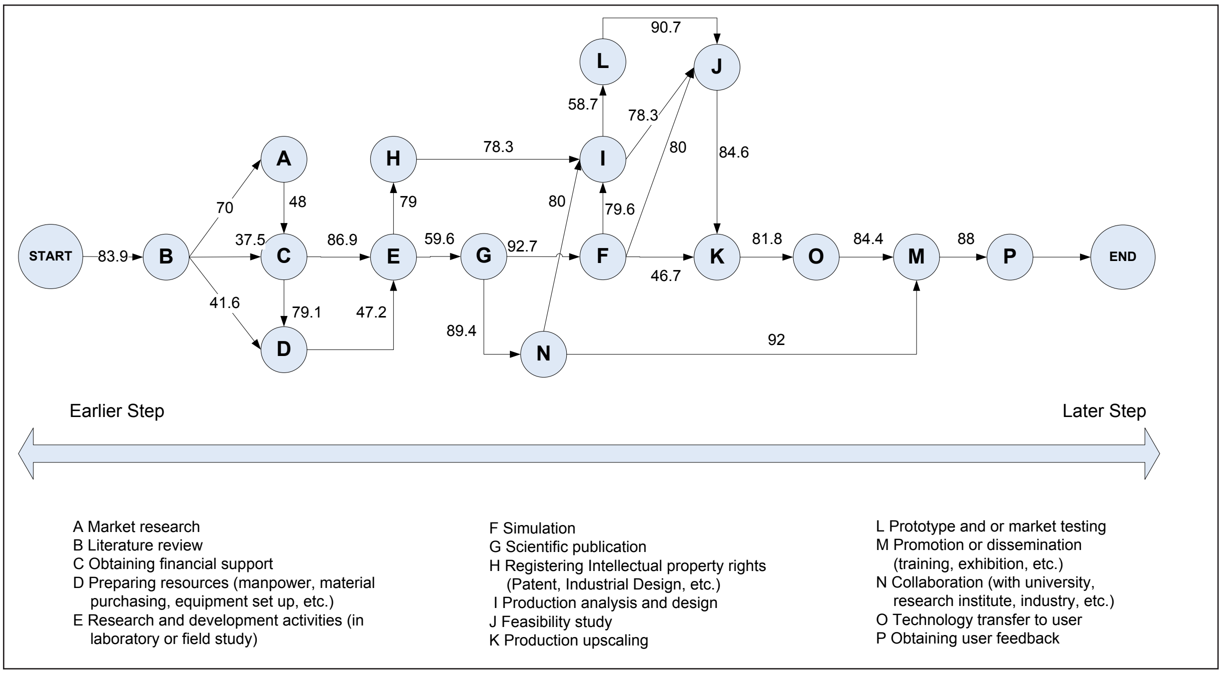

Figure 8. All technology transfer steps with inefficiency ratios

Table 11.
The inefficiency ratio for adjacent steps

To / From	Inefficiency Ratio for Adjacent Steps															
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
A			48	97		79.6										
B	70		37.5	41.6												
C				79.1	86.9			94.5								
D	86.8		90.7		47.2	92.0								75.0		
E				76.5			59.6	79.0								
F									79.6	80.0	46.7	96.5				
G						92.7						71.2		89.4		
H	77.8			88.9	96.5	87.7			78.3					78.1		93.4
I							77.8			78.3		58.7		92.8		
J							79.4		92.2		84.6					
K									96.0			81.8		95.6	81.8	
L								93.5		90.7				90.5		80.0
M																88.0
N									80.0	91.4			92.0			86.4
O													84.4			
P								76.8			96.0				96.1	

The inefficiency ratio for adjacent steps can be seen in Table 11. The data for inefficiency was obtained by calculating the average efficiency for relevant respondents who selected the two consecutive steps, then converted to the inefficiency ratio using Formula (10). The complete route of technology transfer steps with their inefficiency ratios are depicted in Figure 8. The inefficiency ratio for each step is written on each node. The first node is marked with “Start” and the last node with “End”. Both of them are only to indicate the starting and ending point of the steps, hence no inefficiency score were indicated.

d. Step 4: Exploring the most efficient route with the Dijkstra algorithm

From Figure 8, it can be seen that many alternative routes for technology transfer are available. For instance, in this study, we will take a route from Start to E. There are 5 (five) possible alternatives from Start to E as follows:

- 1st route: Start → B → A → C → E
- 2nd route: Start → B → A → C → D → E
- 3rd route: Start → B → C → E
- 4th route: Start → B → C → D → E

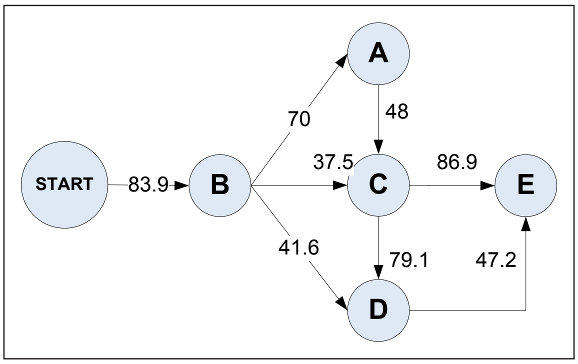

Figure 9. A Sample Route from Start to E

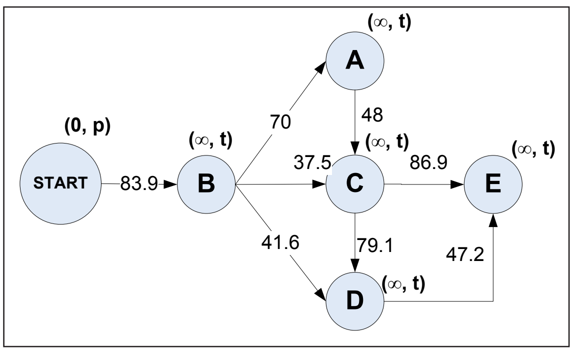

Figure 10. Iteration 1

- 5th route: Start → B → D → E

By implementing the Dijkstra algorithm, we do not need to calculate the overall inefficiency of all routes. Rather, we only need to select the minimum inefficiency for incoming flow at certain nodes.

Iteration 1

- Node ‘Start’ is designated as current node.
- The state of node ‘Start’ is (START, p).
- Every other node has the state (∞, t).

Iteration 2

- The next available node is only B with an inefficiency of 83.9.
- The status label of Node B permanently changes to (83.9, p).
- Node B becomes current node.

Iteration 3

- From the current node (Start, B), Nodes A, C and D can be reached.

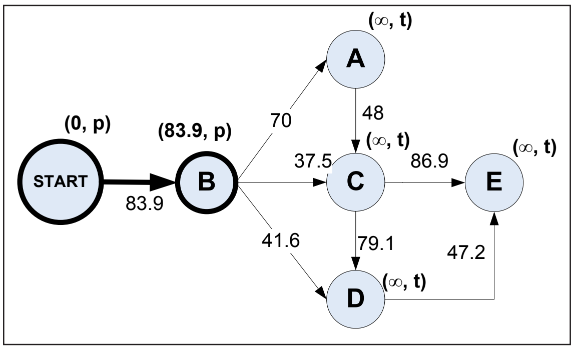

Figure 11. Iteration 2

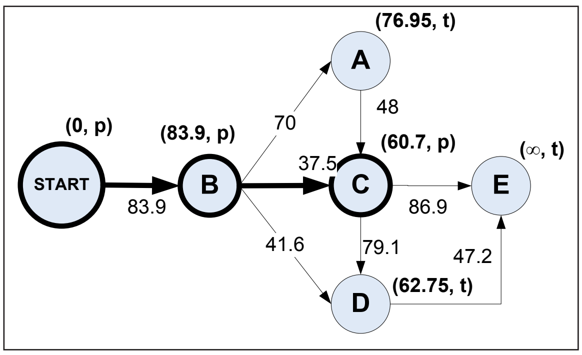

Figure 12. Iteration 3

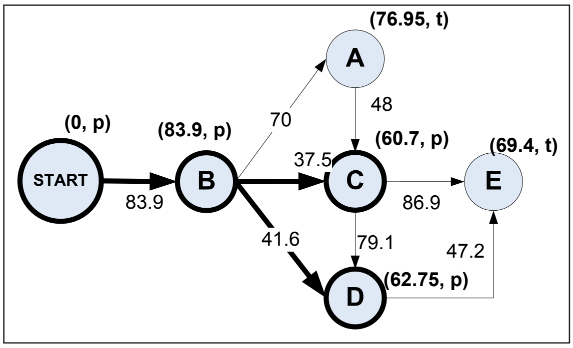

Figure 13. Iteration 4

- Update the distance (d) to related node values for these nodes:

  dA = min{∞, average(83.9+70)} = 76.95

  dC = min{∞, average(83.9+37.5)} = 60.7

  dD = min{∞, average(83.9+41.6)} = 62.75
- Among Nodes A, C and D, flow through Node C has the smallest inefficiency value on average.
- The status label of Node C permanently changes to (60.7, p), while the status of A and D remain temporary.
- Node C becomes current node.
- Since the route has not reached the end, we continue to the next iteration.

Iteration 4

- From current route (Start, B, C), Nodes D and E can be reached. Node E can be connected to from C, while D can be reached from B or D.
- Update the distance values for these nodes:

  dD = min{62.75, average(83.9+37.5+79.1)} = 62.75

  dE = min{∞, average(83.9+37.5+86.9)} = 69.4
- Among the nodes D and E, flow through node D has the smallest inefficiency value in average. The flow to node D come from node B.
- The status label of Node D permanently changes to (60.7, p), while the status of E remain temporary.
- Node D becomes current node.
- Since the route has not reached the end, we continue to the next iteration.

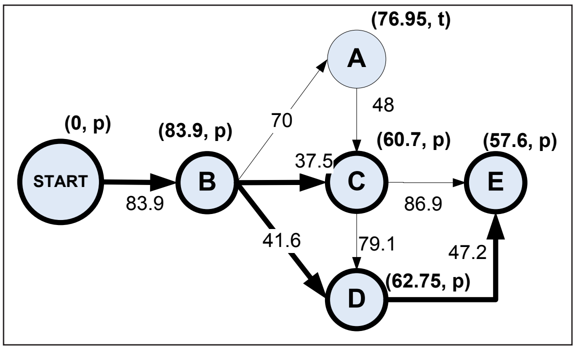

Figure 14. Iteration 5

Iteration 5

- From current route (Start, B, C, D), the next achievable node is E, which can be reached either from C or D
- Update the distance values for these nodes:

  dE = min {69.4, average (83.9 + 41.6 + 47.2)} = 57.6
- Flow to Node D has the smallest distance if come from B.
- The status label of Node E permanently changes to (57.6, p)
- Node E becomes current node
- The route has reached the end (E) so we stop with this iteration.

From this example, we found the least inefficiency ratio in the route Start → B → D → E with the average score 57.6 (or average efficiency ratio = 42.4%).

The next step can be calculated using a similar procedure used to obtain the result in Figure 15.

e. Step 5: Recommending a model for best practice

According to Figure 15, it can be seen that the shortest route, i.e. the route with the least inefficiency ratio, is B → D → E → G → F → K → O → M → P with an average inefficient score of 69.5%, or an efficient ratio of 30.5%. This route, the most efficient, is constructed further in Figure 16.

This constructed route reflects the real conditions of research and development on essential

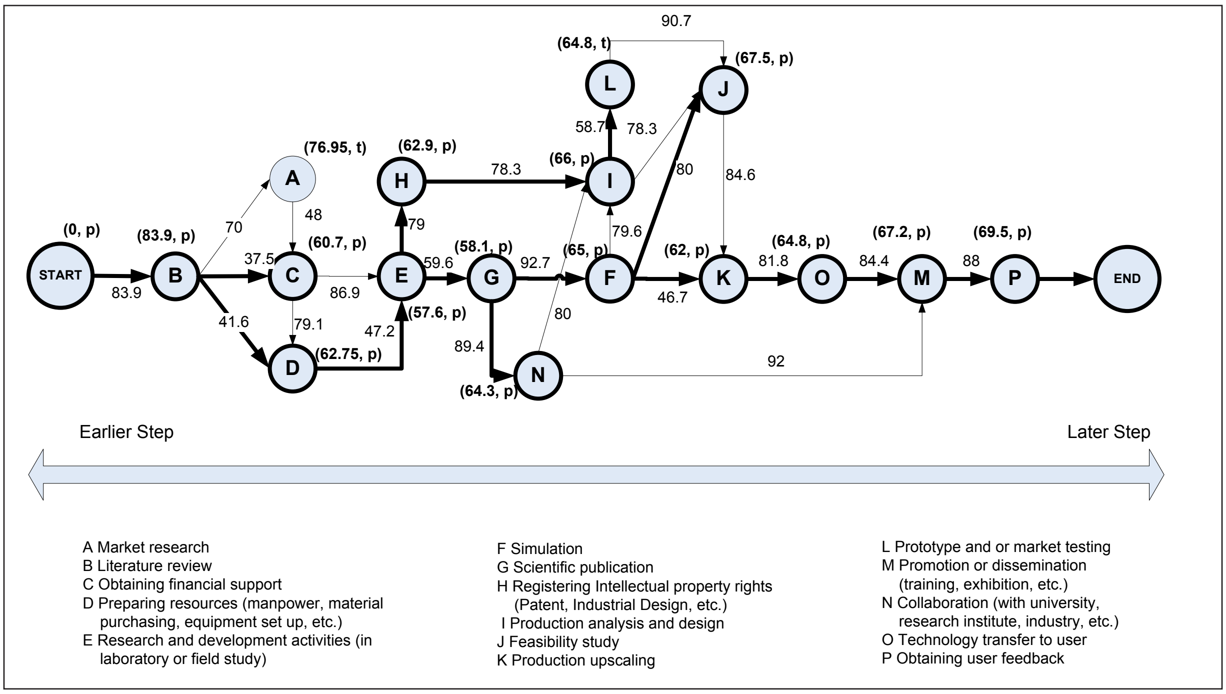

Figure 15. The route of technology transfer steps using the Dijkstra algorithm

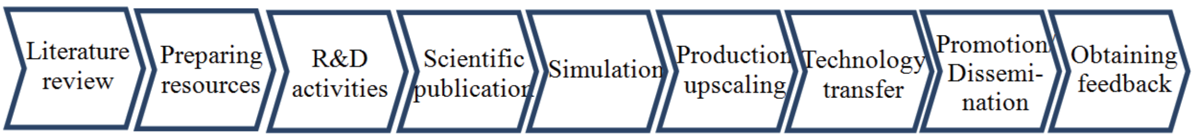

Figure 16. The most efficient sequence of technology transfer steps

oils in RCC LIPI. Many research projects begun with literature reviews, particularly on technical aspects rather than market study. Traditional methods of extraction of essential oils have been discussed in a large amount of the literature; these are the methods most widely used on a commercial scale. To enhance the technology, literature review should be performed more deeply to explore the possibilities of innovation. From the perspective of research, market study may not need to be performed efficiently, and this step can mostly be elaborated within the literature review. In addition, with technological advancements in RCC LIPI, new techniques have been developed. These have not been widely used in commercial production of essential oils but are considered valuable in certain situations, such as the production of costly essential oils in a natural state without any alteration of their thermosensitive components or the extraction of essential oils for micro-analysis.

After performing R&D, scientific publication is viewed as the most efficient next step to continue. It is also supported by the other finding that publishing papers and reports is the key channel through which university research impacts industrial R&D (Cohen, Nelson & Walsh, 2002).

From Table 5, it can be seen that the average efficiency with conventional technology transfer steps is 13.93%. Using the proposed step and algorithm, the average efficiency is improved to 30.5% or an increase of 118.88%. It is rational as the algorithm has selected the best steps to obtain the most efficient route in sequential order.

The recommended model of efficient technology transfer steps should not be viewed as the ideal steps for innovating. Rather, it should be considered as one of the best practices available for finding efficient steps in performing research and development. Those other steps that are not included in the model do not mean that they are not important. They may be important or – in some cases – have more importance. However, to perform these steps, more detailed attention should be given as inappropriate allocation of resources and lack of time and risk control may lead to decreasing overall efficiency.

V. CONCLUDING REMARKS

This study has contributed to the development of science and technology by improving technology transfer performance through: (i) identifying the steps required for technology transfer; (ii) determining performance indicators to measure the efficiency of technology transfer; (iii) sorting the required technology transfer steps in sequential order using the case of essential oil research in RCC LIPI; (iv) investigating for the most efficient route using the Dijkstra algorithm; and finally (v) recommending a best practice model for technology transfer.

In this study, 16 steps have been identified for the process of technology transfer in RCC LIPI. The indicators for measuring step efficiency are cost, time, risk and benefit. Among the abovementioned 16 steps, research and development activities in the laboratory were perceived to have the highest cost, the highest risk and take longest time. Scientific publication is the step with the highest benefit toward technology transfer.

Based on the case of essential oil research in RCC LIPI, these 16 steps have been constructed into a number of route alternatives. By deploying the Dijkstra algorithm, a recommended model containing the most efficient route has been obtained. Compared to conventional methods, the efficiency rate of technology transfer can be increased twice, thus innovation can likely be performed much better.

The prospects of this approach include implementation in technology transfer projects, such as for selecting the route which has shortest time, least cost, highest benefit, etc. Further improvements in the future can be made by improving the algorithm to find the most efficient route faster, developing more indicators to measure efficiency and expanding the research scope to find more generic routes for efficient innovation.

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