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Report

Possibilities of using barcode and RFID technology in Thai timber industry

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Abstract: The Thai timber trade is under increasingly competitive pressure given the international export commitments and simultaneous adherence to a sustainable forest management model, as required by legislation such as the European Union Forest Law Enforcement, Governance and Trade and the European Union timber regulation. Thailand, therefore, needs to build standards that can facilitate traceability in the timber trading system. Timber traceability provides assurance that a certain timber product has been manufactured from legal and sustainable sources. Auto-identification is becoming a common technology in product traceability, particularly the use of barcoding and radio-frequency identification (RFID), which have been used in various industries but is still rarely applied in the forest industry. Therefore, the aim of this study is to investigate the possible application of a barcode and an RFID system in the Thai timber industry and to identify the most favourable technology for traceability. The results indicate that RFID is a more preferable identification method in terms of efficiency and user acceptance. However, the cost of an RFID tag should be reduced to 15 baht/tag or less. Barcodes are not suitable for timber products, at least in the context of the Thai timber industry, even though they are used for other purposes. RFID, on the other hand, provides several benefits throughout the whole supply chain compared with barcodes and other conventional identification systems.

Keywords: auto-identification, barcode, RFID, hammer branding, Thai timber industry, timber traceability, chain of custody

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INTRODUCTION

The wood supply chain consists of a series of handling and processing stages, beginning with standing trees in the forest and ending with finished wood products. A well-designed chain of custody (CoC) should determine a particular wood product's origin, its location at any given point in time, its intended destination, and its scheduled arrival time. CoC systems must be based on the principles of identification, segregation and documentation [1]. CoC systems are thus essential components in any effort that aims to reduce illegal logging, which is one of the most common problems in the forestry sector [2]. Major trading partner countries such as those in the European Union (EU) have taken the measure of establishing the EU Forest Law Enforcement, Governance and Trade to ensure that all timber products are legally imported and traded with good governance. In 2013 the EU set up measures under the EU timber regulation to stop the circulation of illegally logged wood in the EU. The EU timber regulation due diligence system includes the following three elements to minimise illegal logging: information, risk assessment and risk mitigation. Other regions have also put forth regulations including the United State Lacey Act, the Asia Forest Partnership, and the East Asia Forest Law Enforcement and Governance, all of which have had a significant impact on Thai entrepreneurs who export timber and timber products.

A proper wood traceability system plays an important role in fighting illegal logging and ensuring that wood products are derived from sustainable sources. The traceability of timber also provides a means to verify the CoC and the origin of timber and thus helps in preventing illegal logging and in promoting sustainable forestry practices [3,4].

Automatic identification (auto-ID) has become a popular solution for tracing various kinds of products including those in the wood industry. Tracking technologies vary from simple methods to sophisticated technologies, such as conventional painting and chisel labels, hammer branding, attached plastic or paper tags, barcodes, magnetic stripe cards, smart cards, chemical and genetic fingerprinting, and radio-frequency identification (RFID) [1,5]. Barcoding and RFID are the most popular identification technologies in forest industries including those in Finland, Sweden, the US, and South Africa [5–10].

Comparisons of different identification technologies and technology reviews have been carried out globally [1,8,10]. In Africa (Liberia and Guyana) every harvestable tree and all timber are required to carry a barcode throughout the supply chain, from the forest to the point of utilisation [12]. Recently, there has been a substantial increase in the number of applications and implementations of RFID. RFID has been tested for its ability to control and optimise timber logistics [13]. Gjerdrum [14] studied the costs of tracing using RFID in the sawmill industry. The identification performance of RFID has been estimated to be around 99% in Finland's forest industry [15]. Another study reported on the traceability of timber throughout the supply chain while searching for opportunities to improve RFID tags in order to increase their tolerance to extremely cold weather [3]. Picchi et al. [16] found good traceability of logs with RFID tags after cable yarding. The application of RFID in the wood supply chain has been examined with regard to whether the investment cost is acceptable [6,17]. Despite several positive results, Favre [18] pointed out that RFID involves costs that are too high and that the maximum readout range was not long enough.

Even though Auto-ID has become a powerful technology that facilitates the identification of products in timber production, in Thailand simpler methods like hammer branding still dominate. Thai teak timber sales normally use the tree length method. The current log identification method in

Thailand involves the following steps. The felling of trees is done manually using a chainsaw. The felling is followed by the removal of branches, and the logs are then placed on the roadside for storage and subsequent transportation to the log landing. At the log landing, workers measure the log diameter and log length and mark the position where the logs are cross-cut into separate log products, and the log information is manually recorded on paper. Each log is stamped with two different hammers: a log ID and the forest plantation logo. The log data are then manually entered into a computer. Hammer branding is quick and easy to apply; however, it offers low security and reliability, as it is very easy to introduce human error. Human errors are commonly unclear digits on the log or mistakes during data recording. This problem has resulted in the demand for studies on the implementation of new identification technologies. There is room for improvement in terms of efficiency, user acceptance and cost.

The aim of this study is to investigate the barcode and RFID methods implemented in Thai logging conditions and compare them with the conventional method. The comparison covers aspects of work efficiency, user experience and cost analysis. For future changes in the CoC in the Thai timber industry, it is important to investigate the potential implementation of Auto-ID systems.

MATERIALS AND METHODS

Study Area Location and Identification Techniques

The experiment was carried out on timber harvested from the Thung Kwien (18°20'16"N, 99°15'04"E) and Mae Mye (18°29'42"N, 99°38'44"E) forest plantations. Both teak plantations are Forest Stewardship Council certified and are located in Lampang province, Thailand. This study involved high-value teak timber as a pilot project. The experiment was carried out on a part of the supply chain (from the landing to the mill). Three log identification technologies were examined: (1) hammer branding with manual recording, (2) barcoding and (3) RFID (see illustrations in Figure 1). Each method was analysed on the basis of three key measurements: efficiency, user acceptance and cost [19].

In hammer branding, logs are manually marked with specific hammers, as indicated in figure 1A. This simple method involves verification using a huge number of symbols, usually identified locally. Hammering is easy and quick to impress, but the markings are often difficult to read. In Thailand logs are typically stamped with the log ID, year of harvesting, and the logo of the plantation.

Barcoding uses a combination of black and white bars representing different text characters generated by a set algorithm. This identification method is simple and low in cost. However, it is difficult to apply widely in the wood industry and can lead to problems with traceability, e.g. in Scandinavia's harsh logging conditions, where the logging process is fully mechanized and partly automatised [3].

RFID technology facilitates the identification of objects by employing radio waves to receive and send data. Barcoding and RFID are similar techniques in that they automate the data collection process. RFID tends to be valuable in creating greater visibility in the timber supply chain, higher product velocity, increased transportation management efficiency, improved quality control, and reduced human error. However, RFID does not seem to be beneficial economically [20].

Figure 1. Different techniques used in the study: (A, B) hammer branding, (C) barcoding and (D) RFID.

Efficiency

In general a working group is composed of five to eight forest workers, and each worker has an allocated job responsibility. In the system studied, log measurement was executed by three workers who attended to painting and stamping work as well. Another three-person subgroup carried out cross-cutting work. Log classification and data recording were both managed by one person. In the analysis, delays between work elements and the effective working time (E_0) were measured. Immediately after processing the tree into logs, barcode labels or RFID tags were fixed to the log ends. Once the tags were fixed, the log information (log ID, diameter and length) was individually registered at the log landing. The number registered on the tag was read and linked with the log information [13].

The study details were recorded directly in the field for all three identification methods. During the study, the work cycle was broken down into work elements (Table 1). Each work element and the amount of time it required were recorded (cmin), and snapback timing was applied in the timing studies. The expected total time was computed as the sum of the work element times and is mathematically represented in Eq.1 for hammer branding and in Eq.2 for barcoding and RFID. The duration of various work elements differed depending on the identification method.

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Table 1. Description of work elements for the three techniques used in the study

Work element	Term	Description	Remark
Log measurement	T_M	Begins when worker starts measuring the log (diameter and length) and ends when worker writes the number on the log using chalk in hammer branding. Chalk is not used with auto-ID systems.	1,2,3*
Cross-cutting	T_{CC}	Begins when worker starts cutting the log with chainsaw and ends when cross-cutting is finished.	1,2,3
Painting	T_P	Begins when worker starts dipping paintbrush in paint and ends when worker stops painting.	1
Classification	T_{CL}	Begins when worker starts the classification of log and ends when worker makes decision on which category the log is to be allocated to.	1,2,3
Recording	T_R	Begins when worker starts to walk the log to be recorded and ends when worker stops writing the log details.	1
Stamping	T_S	Begins when worker starts to move the log to be stamped and ends when the worker stops stamping the log ID, year and plantation logo.	1
Input data (manual)	T_{IM}	Begins when worker starts opening a new file in the computer and ends when worker has entered the last data into the file.	1
Nailing	T_N	Begins when worker starts with the process of generating barcode label or RFID tag and ends when worker has nailed the label or tag onto the log.	2,3
Scanning	T_{SC}	Begins when worker starts reading barcode or RFID and ends when worker has scanned the barcode or RFID.	2,3
Input data (automatic)	T_{IA}	Begins when worker starts adding log information to the program installed on a handheld computer and ends when the data input is finished.	2,3

*1 = Conventional method; 2 = Barcoding; 3 = RFID

$$T_{TOTAL} = T_M + T_{CC} + T_P + T_{CL} + T_S + T_R + T_{IM} \quad (1)$$
$$T_{TOTAL} = T_M + T_{CC} + T_{CL} + T_N + T_{SC} + T_{IA} \quad (2)$$

A readability test was applied to examine the effect of dirt and moisture that could influence the readability of the barcode label and RFID tag (Figure 2). Labels and tags were soaked in water for half an hour before testing their readability. Three levels of dirtiness were applied: light, moderate and heavy. The level of dirtiness was determined as follows: light when the dirt covering the tag was less than 30% of the tag surface area, moderate when the dirt covering the tag was between 30 and 70% of the tag surface area, and heavy when the dirt covering the tag was greater than 70% of the tag surface area, including damaged barcodes.

Human error was randomly examined among the remaining log piles at the landing using a sample of 60 logs in three log piles. Log information obtained from the database was compared with remeasurements of log dimensions in the forest. Remeasurement was undertaken using the same procedure as that carried out by the forest workers. The measuring equipment consisted of a diameter tape and length measuring tape, and the measured log diameter and length were used to calculate the log volume. Errors were categorised as underestimations or overestimations based on the actual measurement.

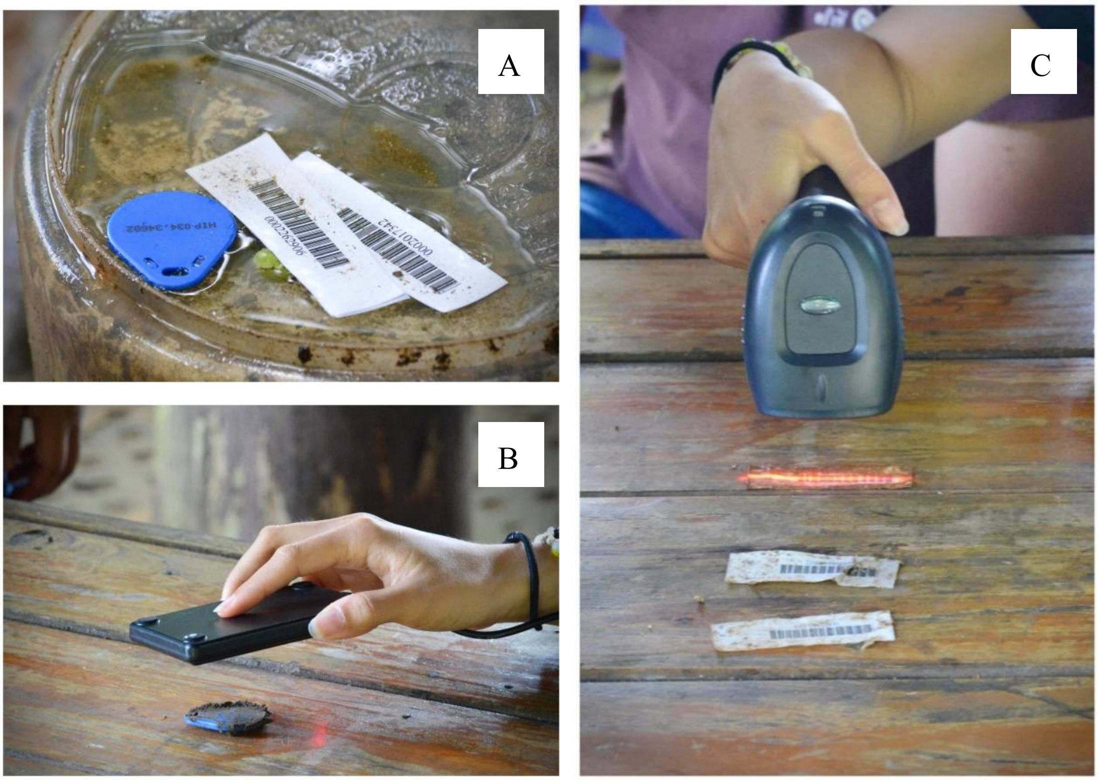

Figure 2. Readability test: (A) tags and barcodes are soaked in water before being read in order to study their moisture resistance; (B) readability testing of dirty RFID tag; (C) levels of dirtiness of barcodes assessed are heavy, moderate and light.

User Acceptance

User acceptance was tested based on a questionnaire which was divided into two sections: (1) experience and expectation before using barcode and RFID technologies and (2) satisfaction after using barcode and RFID technologies. Questionnaire interviews were conducted with all the participants involved in the field experiment.

Cost

A cost analysis was performed using a break-even analysis [11]. Different assumptions were made with regard to the changes involved in costs. The analysis assumed the transportation of 3000 m^3 of timber annually with different log diameters and lengths. The analysis considered 14 log dimension classes with three different log lengths (2, 4, and 6 m.). Tag price was a highly variable cost in this analysis. The number of tags was calculated based on the annual log volume and the average size of the logs in this study. The current RFID tag price is around 25 baht/tag. A suitable tag price was determined by proportionally decreasing the tag price until a break-even value was found.

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RESULTS

Efficiency

The relative working times and their distribution among the work elements are presented in Table 2. The observations of T_M, T_{CC} and T_{CL} work elements were used as fixed values for all three methods. The time spent on these work elements was about 1 minute and 9 seconds. The hammer branding method consisted of fewer observations than the Auto-ID systems because it is a time-consuming method. The variances of T_P, T_R and T_S were large for the conventional method, but in some cases delays also occurred with barcode scanning (T_{SC}).

Table 2. Lead time (seconds) according to work elements

Work element	Term	Min	Max	Mean	S.E.	S.D.	Variance	n	
Log measurement	T_M	1.12	201.6	42.45	3.51	41.68	1736.95	141	All
Cross-cutting	T_{CC}	2.40	81.45	20.58	1.18	15.45	238.60	170	
Classification	T_{CL}	1.14	36.00	5.91	0.62	6.51	42.43	111	
Painting	T_P	1.80	40.20	10.22	0.91	7.01	49.08	59	Hammer
Recording	T_R	6.51	89.93	31.76	2.96	21.75	473.09	54	
Stamping	T_S	7.80	176.40	38.27	4.12	35.68	1273.41	75	
Input data (manual)	T_{IM}	1.17	6.86	2.52	0.06	0.82	0.68	180	
Nailing	T_N	2.23	22.66	7.38	0.24	3.32	11.01	194	Barcode
Scanning	T_{SC}	0.50	56.38	7.90	0.59	8.30	68.84	199	
Input data (automatic)	T_{IA}	0.50	55.55	9.74	0.36	5.04	25.39	198	
Nailing	T_N	2.24	16.10	6.41	0.17	2.46	6.05	197	RFID
Scanning	T_{SC}	0.56	5.80	2.23	0.08	1.08	1.16	199	
Input data (automatic)	T_{IA}	3.64	20.08	8.60	0.17	2.41	5.83	191	

The work cycle time distribution identifies which work elements need the most improvement. The most time-consuming work element needs to be focused on in the work cycle because of potential time savings and error reduction. Such error-prone steps include marking the second, identical code number on the logs and transcribing data from paper to computer. It was observed that log measurement and cross-cutting accounted for similar proportions of the overall time in all identification methods, while it was clear that recording and stamping were the major time-consuming elements in hammer branding (Figure 3). The average work cycle time for hammer branding (conventional method) was 151.71 seconds or 2.53 minutes. Barcode identification took 93.97 seconds per work cycle, which is 62% of the lead time measured in the conventional method. RFID was the fastest identification method with an average time of 86.18 seconds per work cycle, which is almost half of the lead time of the conventional method.

Human error was randomly examined among log piles, and the errors identified included mistakes made when reading numbers, painting, stamping and recording (Figure 4). The results reveal that errors can occur in every work element.

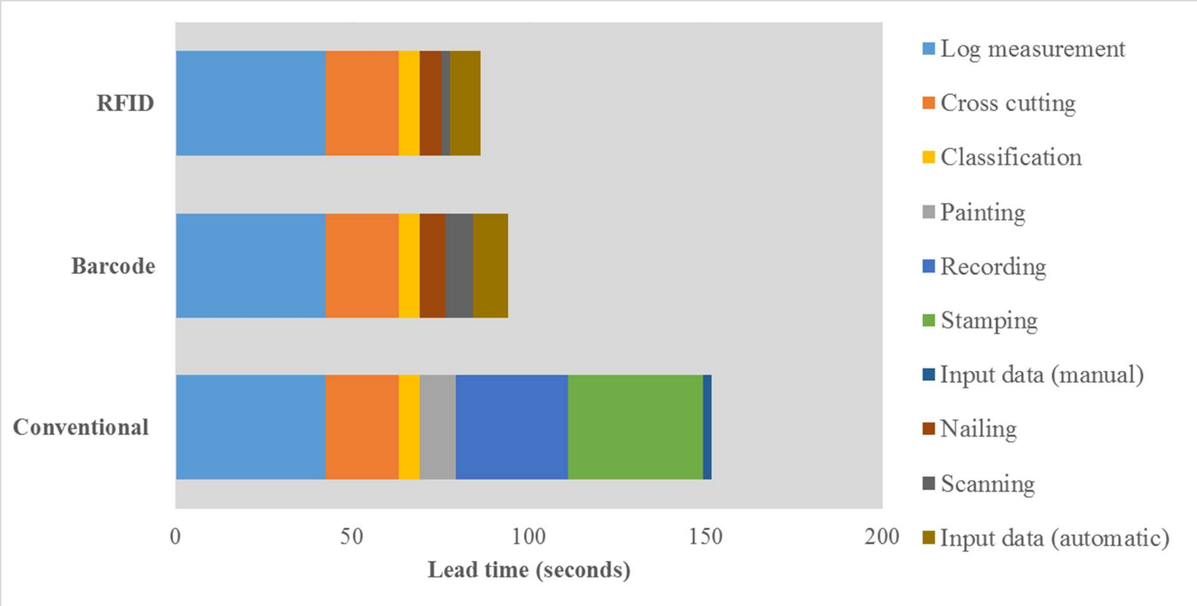

Figure 3. Lead time distribution according to work method

Figure 4. Types of errors during the hammer branding method: (A) both number codes should be the same; (B) the number indicating the diameter of the log is unclear; (C1, C2) pictures of a log and its mirror image with the length of the log painted on it. Depending on the visual angle, the number can be interpreted differently, leading to an error.

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The study also considered the degree of obstacles which may impact readability, such as moisture and dirt. The results indicate that the RFID reader could read tags much faster than a barcode. The barcode reader usually took several seconds or more to complete the reading cycle. Contamination from water and soil material did not have any effect on tag readability when using RFID. The reading time was less than a second despite dirtiness. In contrast, moisture and varying degrees of dirtiness significantly impacted the barcode readability. The moisture extended the reading time by 3–5 seconds. With light level of dirtiness, reading time was 10–60 seconds. With moderate level, reading time increased to over 60 seconds, and with heavy level, reading was impossible. Once a barcode label was damaged, it was no longer accessible. The barcode could easily be damaged and detached during the logging operation because it is a paper sticker. Another problem with the barcode reader occurred when reading the barcode under bright, sunny conditions, which required the use of a scanner hood or shade in order to facilitate scanning.

User Acceptance

The questionnaire was filled out by all people involved in the experiment. Most of the workers expected that the barcode method would be faster and easier to use compared with the other work methods (Table 3). After the experiment, the opinion of the workers noticeably changed, and RFID was the preferred technology in terms of its reading ability and ease of use. However, some respondents still considered the conventional method to be more suitable for identification since law enforcement requires that every log must contain a serial number marked by hammer branding.

Table 3. User expectations and satisfaction rating, n = 18

Topic	**Conventional** (%)	**Barcode** (%)	**RFID** (%)	**Remark**
Faster reading ability	-	61.1	38.9	Before experiment
Easy to use	-	72.2	27.8	
Faster reading ability	-	-	100.0	After experiment
Easy to use	-	16.7	83.3	
Most suitable for timber industry	22.2	38.9	38.9	
More favourable technology	5.6	22.2	72.2	

Cost

Different scenarios using conventional, barcode and RFID methods were compared based on the assumed annual log volume of 3000 m^3/year, as shown in Table 4. The equipment cost included the total cost of the tags and the price of the one-reader device. Additionally, maintenance costs were included in equipment costs. The price of RFID tags was high, even though the time savings were significant in terms of the number of working days. The break-even point analysis result indicated that an RFID tag that costs lower than 15 baht/tag would be cost-competitive with the other methods.

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Table 4. Scenario analysis (based on annual timber removal of 3000 m^3/year)

Aspect	Unit	Conventional	Barcode	RFID
Labour requirement	People	11	7	6-7
Lead time	Minutes	2.53	1.57	1.44
Productivity	Logs/hour	24	38	42
Working day	Days	176	109	100
Labour cost	Baht	38,720	23,980	22,000
Equipment cost	Baht	-	11,620	506,500

The amount of timber removal required to compensate for the cost of the RFID tags varied according to log size and length. RFID cost was cheaper with larger and longer logs compared with small and short logs (Table 5). For example, with a log diameter of 40–44 cm and a long log (6 m), the RFID expenses were comparable to those incurred using the other methods with 1600 m^3 timber removal, whereas 2520 m^3 of short logs was required to achieve the break-even cost.

Table 5. Sensitivity analysis of log dimension and log length of the required timber removal (3000 m^3) to cover the RFID cost. The values show how many cubic meters must be harvested to cover costs. Empty cells indicate that the break-even point is higher than the annual logging volume.

Log girth	Log length (m)		
(cm)	2	4	6
30–34		2931.6	2439.0
35–39		2608.7	1960.8
40–44	2521.0	2247.2	1596.6
45–49	2105.3	1549.3	1263.2
50–54	1716.7	1206.9	1153.9
55–59	1443.3	1030.9	923.1
60–64	1219.5	975.6	909.1
65–69	1071.4	857.1	851.1
70–74	909.1	819.7	800.0
75–79	849.1	754.7	750.0
80–84	744.7	714.3	714.3
85–89	722.9	638.3	645.2
90–94	675.7	606.1	571.4
95–99	597.0	540.5	454.6

DISCUSSION

The results reveal that several work elements, i.e. painting, recording and inputting data, were duplicated in the same dataset. The same log information was repeated many times in several work elements – the greater the number of repeated actions is, the higher the chance of an error becomes. Auto-ID (barcoding and RFID) has great potential for eliminating unnecessary work elements and reducing the lead time as it is based on paperless documentation. Most human errors in this study were underestimations of the log diameter, length and volume. The average error in the log volume estimation was about 0.008 m^3/log. A forest plantation generally produces 30,000–40,000 logs annually; the plantation would therefore lose at least 240 m^3 of timber, which could be a substantial economic loss. The limitation of hammer branding is the difficulty in tracing the origin of a product. Without the year of harvesting and forest plantation logo, it is impossible to determine a log's origin. Furthermore, hammer branding identification makes it difficult to recheck the inventory and is unsuitable once the timber has been loaded onto a truck.

Based on user acceptance, the majority of participants involved in the study preferred auto-ID over the conventional identification system. Nevertheless, some respondents still preferred the latter system as the Forest Act specifies that every log must be stamped with the plantation logo, log ID and year of harvesting, and each log must clearly have its information (log diameter and length) on a paper record. Consequently, the Thailand forest plantation act is an obstacle to implementing Auto-ID technology as a viable replacement of the conventional identification system. Since 1941 the act has decreed that every log must be marked with the logo of the company, harvesting year and code number using the hammer branding method, although nowadays it is possible to use more developed techniques to implement these procedures. This study provides valuable information not only about the time consumption of conventional and auto-ID methods, but also about the initial phase during which logs are measured, cross-cut and classified.

The use of barcodes printed on paper stickers presents some disadvantages as the scanner needs to be in a direct line of sight with the barcode and has to be close enough to the sticker for a successful read-out. It was also found that a barcode is less robust compared with an RFID tag. The barcode is easily destroyed or detached and once it has been damaged, it is not possible to scan the product. For these reasons, a barcode might not be suitable for the circumstances in Thailand unless it is printed on a plastic tag, which would then increase the operating cost.

RFID seems to be the most promising method for marking logs. However, further development of this technology is needed, particularly with regard to the investment cost. The RFID cost per tag is expected to decrease in the future. This study shows that the acceptable cost is 15 baht/tag, which is consistent with the studies by Timpe et al. [11] and Hogg [8], who concluded that a suitable cost per RFID tag is 13.8 and 20 baht/tag respectively. A lower tag cost equates to a greater profit per unit and reduces the timber volume that must be produced in order to break even. This study has included a traceability survey to assess roadside operations before extending the use of RFID to the whole supply chain (from the logging site to the mill yard). This aspect needs further investigation, although the results are promising.

The recommendations from this study can be categorised into short-term and long-term implementations as follows.

Short-term implementation:

A. The normal RFID tags that are currently available on the market may not be suitable for forestry work. Moisture and dirt are not key barriers to using this technology in the forest, but the rugged working conditions require the development of specific RFID tag housing that is resistant to mechanical impacts and can protect the tag from harsh weather conditions.

B. Relevant regulations need to be updated to allow for methods which are alternatives to hammer branding.

Long-term implementation:

A. The entire supply-chain flow needs to be connected to one system. This will provide system transparency in the near future to facilitate and create a standardised national timber tracking system.
B. Auto-ID may play an important role in the future for tracking standing trees to prevent illegal logging. However, such a standing tree tracking system requires an immense investment with regard to attaching an active RFID tag to every tree and using powerful readers. Once the RFID technology becomes cheaper, it should be possible to implement such a process.

CONCLUSIONS

Auto-ID provides several benefits to workers, supply chain managers, CoC, and the end users of timber products. While the use of barcodes is a general practice in many countries, it does not suit circumstances in Thailand. The most promising identification system is RFID, which has greater benefits compared with the barcode and conventional identification systems. Together with IT and networking technologies, which are developing rapidly, a tablet computer in conjunction with a cloud service system has high potential for being used for data inventory in the forestry sector, given that it is comparatively faster, has fewer errors, and is a paperless system. In addition, tag development is a crucial requirement and should be further tested under different work conditions.

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