別紙４－１（課程博士（英文））

Date of Submission (month day, year) : January 10, 2019

Department	Student ID Number	Supervisors
Environmental and Life Sciences	D 123430	HIROYUKI DAIMON TATSUO OGUCHI
Applicant's name	Dunuwila Mudiyanselage Pasan Tharuka Dunuwila	

Abstract (Doctor)

Title of Thesis	Integration of Process Analysis and Decision-Making Tools for the Sustainability Improvements in Raw Rubber Manufacture (天然ゴム製造における持続可能性改善のためのプロセス分析と意思決定ツールの統合)

Approx. 800 words

Raw rubber manufacture is an industry mainly based in developing countries in South and South East Asia. It has been a prominent source which brings foreign revenue to such countries. Reported as material-, energy-, and labor-intensive, this industry has been confronted with high cost of manufacture, low cost efficiency and various environmental issues. Therefore, the main aim of my research has been addressing these issues through improving raw rubber manufacture to have less material and monetary losses, environmental and negative social impacts. Manufacturing major raw rubber products of crepe rubber, concentrated latex, and ribbed smoked sheets in Sri Lanka has been subjected to this research.

Firstly, crepe rubber and ribbed smoked sheet manufacture were analyzed using a novel method to reach the aim. This method deployed: 1) material flow analysis (MFA), material flow cost accounting (MFCA) and environmental life cycle assessment (ELCA) to quantify material flows and waste, monetary losses, and greenhouses gas (GHG) emissions, 2) Pareto and what-if analyses, information from field interviews and literature to develop improvement options; and 3) re-execution of MFA, MFCA and ELCA to foresee the degree of improvement. Simple cost benefit analysis was also employed to know the financial feasibility of improvement options. In terms of crepe rubber manufacture, water and chemical use found to be the factors affecting monetary losses whereas electricity had been a key driver of GHG emissions. While monetary losses were found negligible in ribbed smoked sheet manufacture, firewood use had been a major factor affecting GHG emissions. Based on field interviews and literature, viable improvement options were developed; for instance, installing water reuse system, re-determining dry rubber content and installing solar panels were proposed for reducing water, chemicals and electricity, respectively in crepe rubber manufacture. To reduce firewood use in ribbed smoked sheet manufacture, an efficient smoke house consuming less firewood was proposed. Improvement options were foreseen to be saving water, chemical, energy and firewood to give remarkable financial and environmental benefits

for both manufacturing lines. Meanwhile, the simple cost benefit analysis indicated that all improvement options were financially feasible.

Secondly, the previous method was further modified to be applied to concentrated latex manufacture. Discounted cash flow analysis (DCFA) and greenhouse gas payback time (GPBT) were integrated in this regard for a detailed economic and environmental feasibility assessment. Novel loss reduction efficiency (LRE) index was also introduced to measure overall efficiency of improvement options. Rubber losses and chemical consumption were found to be main factors affecting monetary losses whereas electricity consumption was identified as a key driver of GHG emissions. Similar to previous research, applicable improvement options were proposed based on field interviews and literature. Extending sedimentation time during the addition of chemicals and installing trap tank were amongst the improvement options proposed for reducing chemicals and rubber loss, respectively. Installing inverters and solar panels were proposed to lower electricity consumption to alleviate GHG emissions. Results were promising as large proportion of monetary losses and environmental impacts were foreseen to be lowered by the proposed improvement options. As per DCFA and GPBT, proposed improvement options were found to be economically and environmentally feasible. Novel LRE index was proven to be effective as it could identified installing trap tank as the best option of all.

Not scrutinizing social impacts of natural rubber manufacture was a major lacuna in both methods; hence, thirdly, we tried performing a social life cycle assessment (SLCA). SLCA is a relatively new discipline and has no designated method or framework published yet. Therefore, a new method based on Analytic Hierarchical Process (AHP) was developed for conducting SLCA. Quantifiability of negative and positive social impacts, and foreseeability of the improvement in social aspect were the key features of this method. This method was used to scrutinize the social impact of workers at a raw rubber factory in Sri Lanka. Results claimed that health and safety, and social benefit/social security of workers were affected thereby jeopardizing working conditions, and health and safety of the country or area. Proposing countermeasures for the identified issues, the extent to which the said aspects can be improved was clarified.