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Mathematical Optimisation Approach for Improvement of Palm Oil Traceability

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Oil palm is recognised as the most productive oil crop with highest oil yield per hectare of agriculture land. The palm oil products generated from oil palm are widely used in our daily life, contributing from food processing, personal care and hygiene sectors as well as the biofuel industry. However, the reputation of oil palm has been declining as it was accused for causing environmental and social problems, such as deforestation, workers exploitation. In order to achieve sustainable production and consumption of palm oil products, traceability of the products is very important. With the complete traceability, the origin location and quantity of palm oil products distributed along the supply chain can be identified and tracked in both the forward and backward directions. In this work, a systematic approach is developed to evaluate the traceability of palm oil products from oil palm plantations to palm oil mills. A scoring system with qualitative measure is developed to quantify the traceability of the feedstock (fresh fruit bunches). A mixed integer non-linear programming model is then developed to maximise the economic performance while tracking the traceability of the fresh fruit bunches in a supply chain. A case study in Perak, Malaysia is solved to illustrate the proposed approach. Two scenarios are solved to determine the maximum traceability and economic performance. In the first scenario, the maximum economic performance of the supply chain is determined as RM 16.8 x 10^6 per annum with traceability of 0.688. In scenario 2, when optimisation objective is set as maximise traceability, the maximum traceability of 0.753 with economic performance of RM 12 x 10^6 per annum is obtained.

1. Introduction

Crude Palm Oil (CPO) is an edible vegetable oil extracted from the mesocarp of the oil palm fruitlet. In 2020, palm oil is the largest production of vegetable oil globally, accounting for approximately 31 % of the global oil and fats production (Yusof, 2021). The global palm oil market is predicted to reach USD 78 x 10^9, expanding at a compound annual growth rate (CAGR) of 3.1 % by 2027 (Grand View Research, 2020). After fresh fruit bunches (FFB) is harvested from the plantation, FFB are sent to the palm oil mills and kernel crushing plant for extraction of crude palm oil (CPO) and crude palm kernel oil (CPKO) (Foong et al., 2019a). A number of biomasses which include kernel cake, empty fruit bunch and palm oil mill effluent are generated during the extraction process (Foong et al., 2019b). The palm-based biomasses can be used as feedstock for combined heat and power (CHP) plant after pre-treatment processes (Lam et al., 2010). CPO and CPKO will then be sent to the refinery to produce refined bleached and deodorized (RBD) palm oil and RBD palm kernel oil (Gibon et al., 2007). As reported by Malaysian Palm Oil Council (MPOC), palm oil is the oil crop with highest yield for a given size of land (MPOC, 2016). However, the reputation of palm oil industry has been declining as it was labelled as the cause of environmental and social problems, such as deforestation and workers exploitation. In order to ensure the sustainable production and consumption of palm oil products, traceability within the entire value chain is important. According to ISO 9000:2005, the term traceability means the ability to trace the history, application or location of that which is under consideration (ISO, 2009). With the implementation of traceability, the origin location and quantity of palm oil products distributed along the supply chain can be identified in both the forward and backward directions.

However, to date, limited literature focus on quantifying and qualifying traceability in a supply chain (Lo et al., 2020). Based on the previous studies, traceability is also yet to be defined qualitatively which can optimised via

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optimisation model. The purpose of this work is to propose a systematic method based on qualitative and quantitative measures to analyse the impact of traceability on the economic performance of a supply chain. A mathematical optimisation model is developed via a commercial optimisation software (Lingo 18.0 with global solver) to demonstrate the proposed approach. The traceability analysis, mathematical formulations, case study, conclusion and future work are presented in the following sections.

2. Traceability Analysis

In this work, a new traceability analysis is developed. Three scoring systems named Operation Confidence Level (OCL), Interaction Confidence Level (ICL) and Traceability Confidence Level (TCL) are introduced to measure the traceability of a material in a supply chain qualitatively and quantitatively. In this work, the traceability of FFB from the plantations to the palm oil mills is presented. OCL, ICL and TCL of such supply chain is showed in Tables 1 – 3.

In this work, Operation Confidence Level (OCL) is defined as operability of an entity, it can be determined based on the track record, certification status of an entity and reliability of the feedstock. Certified entity is refers to as business entity which complies under international or national schemes, such as Roundtable Sustainable Palm Oil (RSPO), Malaysia Sustainable Palm Oil (MSPO). The audit record refers to previous records on transection of FFB. The detailed description for OCL is showed in Table 1.

Table 1: OCL 9-point scales

Score	Description
1	Uncertified entity with no audit record
2	Uncertified entity with non-proven audit record (record < 3 year)
3	Uncertified entity with proven audit record (record > 3 years) but unreliable FFB stocks (deviation of average yearly production > 30 %)
4	Uncertified entity with proven audit record (record > 3 years) but unreliable FFB stocks (deviation of average yearly production <30 %)
5	Uncertified entity with proven audit record (record > 3 years) and reliable FFB stocks (deviation of average yearly production <20 %)
6	Certified entity with proven audit record (record > 3 years) but unreliable FFB stocks (deviation of average yearly production >30 %)
7	Certified entity with proven audit record (record > 3 years) but unreliable FFB stocks (deviation of average yearly production <30 %)
8	Certified entity with proven audit record (record > 3 years) and reliable FFB stocks (deviation of average yearly production <20 %)
9	Certified entity with proven audit record (record > 3 years) and high reliability of FFB stocks (deviation of average yearly production <10 %)

Interaction Confidence Level (ICL) defines the interaction between two interconnecting entities where transactions of FFB happen. ICL can be determined based on the nature of OCL of each involved entity. The ICL score can be calculated via Eq(1) and Table 2 shows the description of ICL based on a 9-point scales. Note that the ICL score will be rounded down to the nearest value for a more conservative approach. In order to achieve ICL of 9, both involved entities are required to be certified with proven audit record for more than three years and high reliability of FFB stocks.

$$\text{ICL} = \frac{\text{OCL of entity 1} \times \text{OCL of entity 2}}{\text{Highest OCL out of the two entities involved}} \quad (1)$$

Traceability Confidence Level (TCL) defines the range of achievable traceability of a supply chain. TCL of each entity can be calculated based on OCL and ICL scores which will be discussed in detailed in the next section. The overall TCL of a supply chain, $\text{TCL}^{\text{Overall}}$ can be determined by taking the average TCL of every entity involved in the supply chain. Table 3 shows the description for TCL point-scales.

Table 2: ICL 9-point scales

Score	Description
1	Both entities with OCL = 1
2	At least one of the entities with OCL = 2
3	At least one of the entities with OCL = 3
4	At least one of the entities with OCL = 4
5	At least one of the entities with OCL = 5
6	At least one of the entities with OCL = 6
7	At least one of the entities with OCL = 7
8	At least one of the entities with OCL = 8
9	Both entities with OCL = 9

Table 3: TCL point-scales

Score	Description
0.10 – 0.39	Minimum confidence level in traceability of palm products
0.40 – 0.59	Undesirable confidence level in traceability of palm products
0.60 – 0.79	Average confidence level in traceability of palm products
0.80 – 0.89	Desirable confidence level in traceability of palm products
0.90 – 1.00	Maximum confidence level in traceability of palm products

3. Mathematical Formulation

The mathematical model is formulated based on mass balance of FFB between different entity from one level to another (plantation *p* –> collection hub *ch* –> palm oil mill *om*) as shown in the superstructure in Figure 1. As shown FFB from plantation *p* both certified and non-certified are first transferred to collection hub *ch* before sending to palm oil mill *om*. Each palm oil mill is given with the minimum and maximum operating capacity. The transportation cost for transferring FFB to palm oil mill along the supply chain can then be calculated.

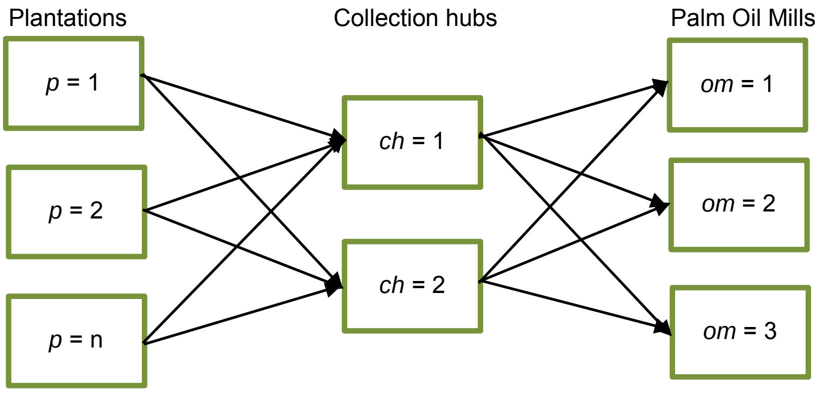


Figure 1: Superstructure of the model

Following the proposed method, OCL of each entity is first defined based on the guideline in Table 1. Next, the ICL of each entity can be calculated using Eq(1), and the TCL of plantation *p*, collection hub *ch* and palm oil mill *om* can be determined via Eqs(2 – 4).

$$TCL_p = \frac{b_p}{n_p}\sum_{ch}\left[b_{p,ch}\left(\frac{ICL_{p,ch}}{9}\right)\left(\frac{OCL_{ch}}{9}\right)\right] \qquad \forall p \qquad (2)$$

$$TCL_{ch} = \frac{b_{ch}}{n_{ch}}\Sigma_{p,om}\left\{\left[b_{ch,p}\left(\frac{ICL_{ch,p}}{9}\right)\left(\frac{OCL_p}{9}\right)\right] + \left[b_{ch,om}\left(\frac{ICL_{ch,om}}{9}\right)\left(\frac{OCL_{om}}{9}\right)\right]\right\} \qquad \forall ch \qquad (3)$$

$$TCL_{om} = \frac{b_{om}}{n_{om}}\Sigma_{ch}\left[b_{om,ch}\left(\frac{ICL_{om,ch}}{9}\right)\left(\frac{OCL_{ch}}{9}\right)\right] \qquad \forall om \qquad (4)$$

where, TCL_p, TCL_{ch} and TCL_{om} are the traceability for certified and non-certified plantations, collection hubs and palm oil mills. $ICL_{p,ch}$, $ICL_{ch,p}$, $ICL_{ch,om}$ and $ICL_{om,ch}$ are the ICL for that involving entity and the other entity. OCL_{ch} , OCL_p and OCL_{om} are the pre-determined OCL score for each entity. Note that $ICL = 0$ if there is no interaction between the entities while $ICL = 9$ (assumed to be highest possible score) if it is a self-interacting relationship. b_p , b_{ch} and b_{om} are binary value and such binary will be equal to 1 for the involved entity.

$$n_p = \sum_{ch} b_{p,ch} \qquad \forall p \tag{5}$$

$$n_{ch} = \sum_{p,om} (b_{ch,p} + b_{ch,om}) \qquad \forall ch \tag{6}$$

$$n_{om} = \sum_{ch} b_{om,ch} \qquad \forall om \tag{7}$$

where, n_p , n_{ch} and n_{om} are the total numbers of interaction between the involving entity and other entity. $b_{p,ch}$, $b_{ch,p}$, $b_{ch,om}$ and $b_{om,ch}$ denote the binary variables on the existence of interaction between the involving entity and the other entity. In another words, the existence of transaction of FFB between the entities.

Next, the overall traceability of the supply chain can then be determined in Eq(8) by taking the average TCL of every entity involved as below. The value computed by the optimisation in Eq(8) will be evaluated against the scale in Table 3 to determine the category of the traceability for the supply chain.

$$TCL^{Overall} = \frac{1}{N} \left(\sum_p TCL_p + \sum_{ch} TCL_{ch} + \sum_{om} TCL_{om} \right) \tag{8}$$

$$N = \sum_p b_p + \sum_{ch} b_{ch} + \sum_{om} b_{om} \tag{9}$$

where N refers to the total number of entities involved in the supply chain.

The economic performance *(EP)* of the supply chain can then be determined via Eqs(10 – 13).

$$G_p = A_1 \sum_{cp} F_{cp,ch} + A_2 \sum_{ncp} F_{ncp,ch} \; \forall p \tag{10}$$

$$G_{ch} = A_3 \sum_{ch} F_{ch} \; \forall ch \tag{11}$$

$$G_{om} = A_4 \sum_{om} (F_{om} X_{om}) \; \forall om \tag{12}$$

$$EP = G_P + G_{ch} + G_{om} - CT_t \tag{13}$$

where, A_1 and A_2 refer to the profit of selling certified FFB and non-certified FFB. $F_{cp,ch}$ and $F_{ncp,ch}$ refer to the amount of FFB distributed from the certified plantations and non-certified plantations to collection hubs *ch*. F_{ch} refers to the total amount of received FFB in collection hubs, ch. A_3 refers to the profit of selling FFB to palm oil mills. F_{om} refers to the total amount of received FFB in palm oil mills. A_4 refers to the profit of selling CPO. X_{om} refers to the conversion of FFB to CPO. G_p, $G_{ch}$and G_{om} refers to the gross profit for both certified and non-certified plantations, collection hub and palm oil mill. CT_t refers to the total cost of transportation.

The optimisation objectives of the proposed model is to maximise economic performance Eq(14) of the supply chain while understand the traceability of FFB and palm oil products.

$$\text{Maximise } EP \tag{14}$$

4. Case Study

An oil palm supply chain case study in Perak is solved to illustrate the proposed approach. In this case study, six certified plantations, five non-certified plantations, two collection hubs and three palm oil mills are considered. Figure 2 shows the location while Table 4 shows the OCL of each participating entities in Perak. Table 5 shows the estimated production of FFB in every participating plantation.

Two scenarios are considered in the case study. Scenario 1 is purely maximise *EP*; while scenario 2 considers maximise *$TCL^{overall}$*. It is to investigate the maximum achievable economic performance and traceability of the supply chain as well as evaluating the relationship between the two parameters.

Table 4: OCL score for each participating entity

Entities	OCL	Entities	OCL	Entities	OCL	Entities	Entities
CP1	9	CP5	9	NCP3	4	CHb	8
CP2	8	CP6	8	NCP4	4	OM1	9
CP3	7	NCP1	5	NCP5	3	OM2	8
CP4	7	NCP2	3	CHa	9	OM3	9

Table 5: Production of FFB in every participating plantation

Plantations	FFB Production (tonnes/day)
CP1	121
CP2	85
CP3	180
CP4	22
CP5	222
CP6	480
NCP1	75
NCP2	33
NCP3	37
NCP4	87
NCP5	40

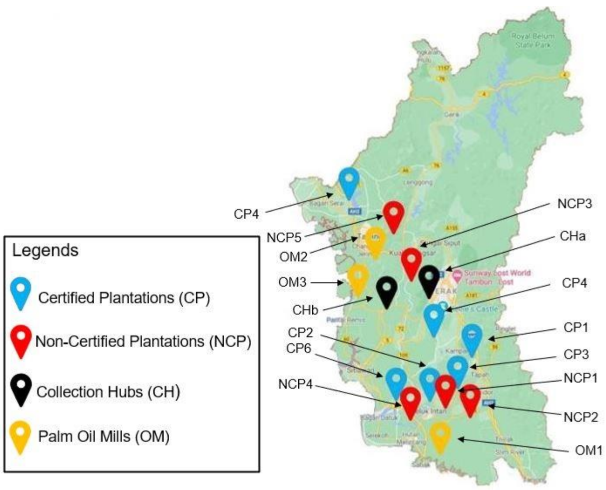
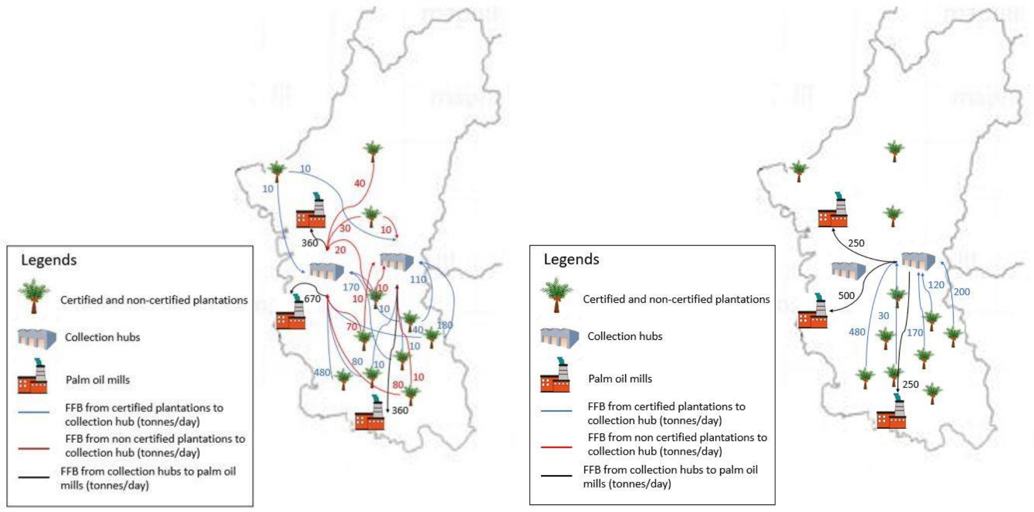


Figure 2: Location of participating entities

In scenario 1, the optimisation objective is set as maximise economics performance without the consideration of TCL. Solving Eq(14) subjected to Eq(1) – Eq(13) in Lingo 18.0 with global solver, the economic performance of the supply chain is determined as RM 562,286 per batch assuming the FFB are harvested in every 10 days after accounting for the cost of transportation. With this, the economics performance of the supply chain is estimated to be approximately RM16.8 x 10^6 per annum. The $TCL^{Overall}$ of the supply chain is determined as 0.688. Referring to Table 3, $TCL^{Overall}$ of this supply chain falls within the average traceability confidence level. Comparing the FFB production in Table 5 and allocation of FFB in Figure 3(a), it is noted that almost all available FFB from the certified and non-certified plantations are processed in palm oil mills. Note that, the shortest travel distance for the distribution of FFB is chosen in order to reduce the transportation cost.
In scenario 2, the optimisation objective is set as maximise $TCL^{overall}$ Eq(8). Based on the optimised results, $TCL^{overall}$ score of 0.753 and *EP* of RM 12 x 10^6 per annum are obtained. It is noted that the $TCL^{overall}$ has increased from 0.688 to 0.753 as compare with scenario 1. According to Table 3, *TCL* of the supply chain is also within the average traceability confidence level. Figure 3 shows the distribution and allocation of FFB across the supply chain for both scenarios. From Figure 3(b), only the plantations and collection hub with the highest OCL score are selected. The existence of interaction only happens between entities that give the highest ICL score in order to achieve maximum $TCL^{Overall}$ while fulfilling the required FFB of each palm oil mills.



(a) (b)

Figure 3: Distribution and allocation of FFB for case study (a) scenario 1 (b) scenario 2

5. Conclusion and future works

A mathematical model is developed to maximise economic performance while analyse traceability of palm oil supply chain. An effective quantitative scale and qualitative measure is presented to define traceability clearly. A case study with two scenarios is solved to illustrate the proposed approach. Based on the optimised result, the maximum economic performance of the investigated supply chain is reported as RM 16.8 x 10^6 per annum while the maximum traceability of the supply chain is reported as 0.753. The model can be used as an effective tool to quantify the traceability of a supply chain. For future work, multiple objective optimisation can be applied to trade-off between economics performance as well as traceability of a supply chain. The mathematical model can be further extended to consider downstream activities of the palm oil supply chain such as the refineries, oleochemicals as well as incorporates the carbon footprint across the supply chain. Works can also be done to implement this model in the other relating industries which account for traceability.

References

Yusof A., 2021, Palm Oil to still be a Powerhouse of Oils and Fats Market: MPOB, New Straits Times <nst.com.my/business/2021/01/659671/palm-oil-still-be-powerhouse-oils-and-fats-market-mpob> accessed 07.12.2020.

Foong S.Z.Y., Goh C.K.M., Supramaniam C.V., Ng D.K.S., 2019a, Input-Output Optimisation Model for Sustainable Oil Palm Plantation Development, Sustainable Production and Consumption, 17, 31-46.

Foong S.Z.Y., Andiappan V., Tan R.R., Foo D.C.Y., Ng D. K. S., 2019b, Hybrid Approach for Optimisation and Analysis of Palm Oil Mill, Processes, 7(2), 100.

Gibon V., De Greyt W., Kellens M., 2007, Palm Oil Refining, European Journal of Lipid Science and Technology, 109(4), 315–335..

ISO, 2009, ISO 9000 Quality management- Fundamentals and Vocabulary', 1–56. International Organization for Standardization <iso.org/obp/ui/#iso:std:iso:9000:ed-3:v1:en> accessed 25.11.2020.

Lam H. L., Foo d. C. Y., Mustafar K., Klemeš J., 2010, Synthesis of Regional Energy Supply Chain Based on Palm Oil Biomass, Chemical Engineering Transactions, 21, 589–594, DOI: 10.3303/CET1021099.

Lo S.L.Y., How B.S., Leong W.D., Teng S.Y., Rhamdhani M.A., Sunarso J., 2020, Techno-economic Analysis for Biomass Supply Chain: A state-of-the-art review. Renewable and Sustainable Energy Reviews, 135, 110164.

Malaysian Palm Oil Council (MPOC), 2016, Palm Oil Fact , Malaysian Palm Oil Council <mpoc.org.my/palm-oil-fact/> accessed 23.05.2021.

Grand View Research, Inc., 2020, Market Analysis Report: Palm Oil Market Size, Share & Trends Analysis Report By Origin (Organic, Conventional), By Product (Crude, RBD, Palm Kernel Oil, Fractionated), By End Use, By Region, And Segment Forecasts, 2020 - 2027 <grandviewresearch.com/industry-analysis/palm-oil-market> accessed 10.05.2021.