Engineering For Social Change
A. Cooper et al. (Eds.)


doi:10.3233/ATDE240949

# Needs Analysis for Time-Based Management in Next Generation Air Traffic Management System

Daichi TORATANI[1], Yoichi NAKAMURA, and Megumi OKA
*Air Traffic Management Department, Electronic Navigation Research Institute, National Institute of Maritime, Port and Aviation Technology, Japan*

**Abstract.** In order to cope with the increased demand for air transportation, air traffic system modernization projects have been undertaken in many countries. In future air traffic, the concept of time-based management (TBM) is being considered to improve the efficiency of air traffic flow. However, TBM is currently only a concept and it is not clear how it should be implemented in practice. This study therefore identifies the potential needs of stakeholders for time-based management. We created a stakeholder value network (SVN) for the stakeholders involved in the next generation air traffic management system and identified the primary stakeholders. We also conducted systemized interviews based on the Kano model with the primary stakeholders to identify their needs. By analyzing the SVN and interview results, the discussion was conducted on the potential needs of the primary as well as secondary stakeholders for a future control system to realize TBM.

**Keywords.** Air traffic management, Needs analysis, Kano model, Time-based management, Stakeholder value network, Transdisciplinary engineering

## Introduction

With several hundred thousand of aircraft flying around the world every day, the skies are crowded with air traffic. To ensure that aircraft can fly safely and smoothly even in congested conditions, a service called air traffic management (ATM) is provided. ATM consists of three main services as follows:

- **Air traffic services** are mainly performed by air traffic controllers. Air traffic controllers maintain appropriate separation between aircraft and ensure smooth traffic flow by issuing timely clearances and instructions to each aircraft.
- **Air traffic flow management (ATFM)** is a demand capacity balancing between air traffic demand and the capacity of airports and air traffic controllers. The ATFM uses various means to restrict traffic flow not to exceed capacity.
- **Airspace management** efficiently manages and allocates airspace to meet the needs of diverse airspace users, both civil and military.

Because ATM provides a wide variety of services to a large number of flights, it is essential that air traffic control (ATC) systems support air traffic controllers. Since ATM also provides services for international flights, ATC systems in different countries are partially interconnected. Although ATM is already supported by such a large and

[1] Corresponding Author, Email: toratani-d@mpat.go.jp.

complex system, it is in need of major changes to meet the increasing demand for air traffic in recent years. In particular, while ATC has traditionally managed air traffic based on sectors, which are finely divided areas for which each air traffic controller is responsible, the International Civil Aviation Organization has proposed the concept of trajectory-based operations (TBO), in which air traffic is managed along an aircraft's trajectory from before takeoff to after landing. Figure 1 illustrates the difference between traditional sector-based operations and TBO. While many countries are researching and developing ATC systems to realize TBO, there are no clear guidelines on how to realize and implement it, as TBO is only a concept.

While some information has been shared, research and development of ATC systems have traditionally been conducted in each flight phase, such as enroute airspace, terminal airspace which is the airspace around an airport, and airport surface. On the other hand, since TBO manages flights along a trajectory from pre-takeoff to post-landing, the discussion of ATC systems should not be strictly divided by flight phase, but should encompass the entire ATC system. In such a situation, the system configuration becomes larger and more complex, and the number of stakeholders increases, making it difficult to achieve consistency across the entire system and to have a common understanding among all stakeholders. Such problems are not limited to ATC systems, but also occur in various modern fields such as finance and inventory management, and are one of the reasons for system development failures.

The ultimate goal of this research is to design a configuration, or in other words, an architecture, of a future ATC system without inconsistencies between subsystems to realize TBO. In particular, we focus on time-based management (TBM), which is an important element of TBO. In order to design an architecture that is consistent across subsystems in a large and complex system, it is important to identify the potential needs that stakeholders have for the target system. To accurately identify the potential needs, it is necessary to apply a systemized needs analysis method, but to the best of the authors' knowledge, there is no previous research that has applied such a method to the development of ATC systems. Therefore, in this paper, we analyzed TBM stakeholders and conducted systemized interviews to identify their needs. The results of the interviews were used to discuss what each stakeholder needs from TBM. In addition, the discussion includes how TBM has the potential to impact society.

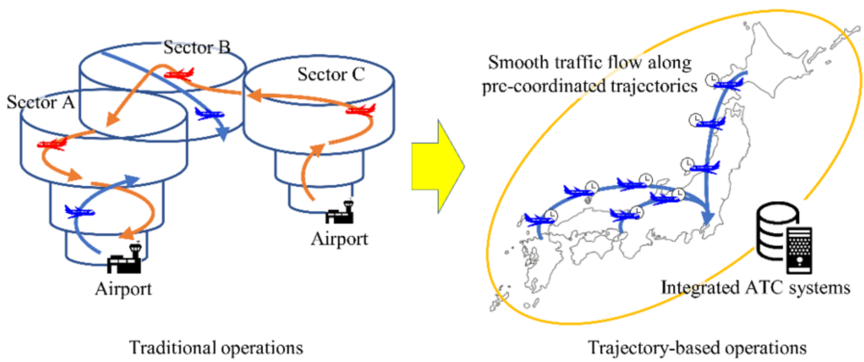


**Figure 1.** Difference between the traditional operations and TBO.

# 1. Trajectory-based management and time-based management

The ICAO defines TBO as follows:

> *A concept enabling globally consistent performance-based 4D trajectory management by sharing and managing trajectory information. TBO will enhance planning and execution of efficient flights, reducing potential conflicts and resolving upcoming network and system demand/capacity imbalances early. It covers ATM processes starting at the point an individual flight is being planned through flight execution to post flight activities.* (Reference [1], p. 12)

Additionally, the Federal Aviation Administration states that TBO consists of TBM, PBN, and enterprise enablers defined as follows:

- *Time Based Management (TBM), which helps manage traffic flows and trajectories by scheduling and metering aircraft through congested NAS resources or constraint points.*
- *Performance Based Navigation (PBN), which enables aircraft to more accurately navigate along their trajectories, and enables decision support tools to improve feasibility of schedules for constraint points as well as achieve greater compliance to schedules.*
- *Enabling Technologies, which expand and automate sharing of common information about aircraft trajectories, and include System-wide Information Management (SWIM), Data Communications, enhanced data exchange and many others.*

(Reference [2])

The role of TBM is to control and manage air traffic based on trajectories that include not only position but also time elements. For example, in TBM, air traffic controllers instruct aircraft to the time at which the aircraft passes over certain waypoints in order to implement ATFM, arrival sequencing, and spacing between aircraft.

# 2. Needs analysis methods

## *2.1. Stakeholder analysis*

To identify the potential needs for TBM, it is necessary to analyze stakeholder relationship, because there may be conflicting needs or trade-offs among stakeholders. While there are several frameworks for stakeholder analysis, we used a stakeholder value network (SVN). SVN is a diagram that visualizes the value chain between stakeholders to clarify what each stakeholder is looking for. To create the SVN, we listed the following stakeholders for TBM.

- **Japan Civil Aviation Bureau (JCAB)** is the civil aviation authority of Japan, which is a division of the Ministry of Land, Infrastructure, Transport and Tourism. JCAB is also Japanese air navigation service provider (ANSP)[2].
- **Airspace users** are the organizations operating aircraft, and their pilots. In the context of TBM, it is almost equal to airlines and their pilots.
- **Customer** includes passenger and, in the case of cargo aircraft, shipper.

[2] ANSP is a public or private legal entity providing air navigation services.

- **Airport community**[3] consists of airport operators and the organizations that support airport operations.
- **ATM support industry** includes ATC system manufacturers and ATM R&D organizations.
- **Adjacent ANSPs** are ANSPs of other countries responsible for airspace adjacent to Japanese airspace.

Figure 2 shows the SVN created based on the stakeholder list above. The airspace users provide air transportation services to their customers in exchange for fares. The airspace users pay air navigation service charges to the JCAB and adjacent ANSPs, and also pay airport charges to the airport community in order to obtain assistance in conducting safe and efficient flights. The JCAB, airport community, airspace users, and adjacent ANSPs share various information, such as flight plans, to ensure smooth air traffic operations. Additionally, they purchase various ATM support systems by paying a price to the ATM support industry. Note that we described that the JCAB into two stakeholder groups: the headquarter and control centers for ATC operations. That is why the headquarter and control center are likely to have different needs for TBM, because the headquarter and control centers have different roles: the headquarter is the regulator and policy maker, while the control centers actually perform ATC.

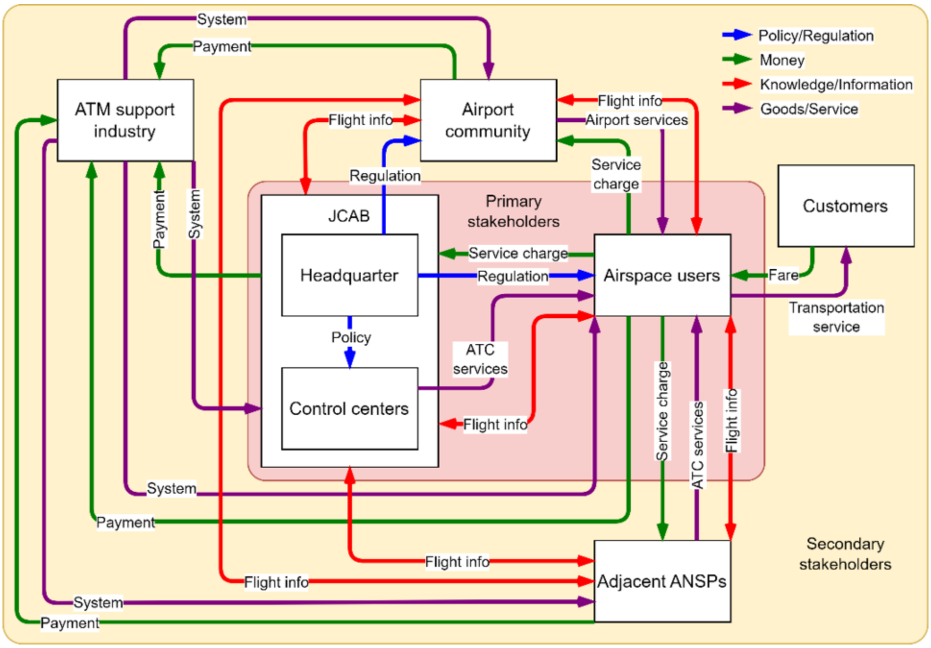


**Figure 2.** SVN for ATC systems to realize TBM.

[3] Airports are managed by different entities, such as the national government, local governments, and private companies, but they are collectively referred to as airport community in this paper.

### 2.2. Interviews with stakeholders

Interviews were conducted to identify potential needs that stakeholders have for TBM. Based on the SVN discussion, the following primary stakeholder groups were identified, and interviews were conducted for them.

- **Policy making group** belongs to the JCAB headquarter and is responsible for making policy decisions such as the introduction of TBM. (2 divisions)
- **ATC operation group** belongs to the department in charge of ATC operations at JCAB. Since the entire Japanese airspace is controlled by several control centers, the control centers that are closely related to the initial introduction of TBM were selected. (4 centers)
- **Airline group** is the primary airspace users in the context of TBM implementation. (2 companies)

The following 11 items were prepared for the interviews. These items are considered to be positively changed by the introduction of TBM or should be considered in developing ATC systems to be implemented to realize TBM. Before the interviews were conducted, these 11 items were presented to the stakeholders to check for missing needs items.

**(a) Time accuracy shared between the air and ground**

The aircraft and the ground ATC system each predict flight trajectories. There may be a discrepancy between the two systems especially in the time at which the aircraft passes over certain waypoints. Since this time discrepancy has a negative impact on ATC operations, it is desirable to share highly accurate time prediction between the air and ground.

**(b) ATC capacity**

As continuously increasing the demand for air transportation, it is required to increase ATC capacity to allow more aircraft to fly.

**(c) Punctuality**

Since punctuality is important in public transportation, it is preferable to improve punctuality.

**(d) Fuel consumption and greenhouse gas emissions**

Rising fuel costs and the need to prevent global warming require reductions in fuel consumption and greenhouse gas emissions.

**(e) Flexibility of choice for airspace users**

Every airline has different preferences, such as reducing flight time or fuel consumption. It is in the airlines' interest to be able to choose flexible flights based on different preferences.

**(f) Fairness among airspace users**

ATC instructions may disadvantage certain flights. Since it is undesirable from the standpoint of fairness to concentrate the disadvantage on a particular flight or airline, fair ATC operations are desirable.

**(g) ATC workload**

As the number of flights increases, the workload of air traffic controllers increases. To maintain the safety and efficiency of ATC, it is desirable to keep the ATC workload low.

**(h) Pilot workload**

Similar to the ATC workload, a lower pilot workload is desirable.

**(i) International interoperability**

Since some aircraft fly through the airspace of several countries, it is desirable for ATC systems to be highly interoperable with the ATC systems of other countries.

**(j) Continuity with current ATC operations and aircraft operations**

Because major changes in ATC operations require significant effort, it is preferable for ATC and aircraft operations to be in continuity with conventional operations wherever possible.

**(k) Compatibility with current or planned ATC systems**

Due to the high cost of replacing ATC systems and their peripherals, future ATC systems should be compatible with current or planned systems wherever possible.

### 2.3. Kano model

We used the Kano model, which is widely used in product development and customer satisfaction surveys, to identify potential needs for TBM [3]. The Kano model can classify customer preferences for the product into 5 categories as follows:

- **One-dimensional quality** causes satisfaction when it is satisfied and dissatisfaction when it is not.
- **Attractive quality** causes satisfaction when it is satisfied, but is considered unavoidable if it is unsatisfied.
- **Must-be quality** is taken for granted when it is satisfied, but causes dissatisfaction when it is not.
- **Indifferent quality** causes neither satisfaction nor dissatisfaction whether it is satisfied or not.
- **Reverse quality** can cause dissatisfaction when it is satisfied or give satisfaction when it is not.

While the reverse quality is a special category, the remaining four categories are generally considered to take precedence in the order of the must-be, one-dimensional, attractive, and indifferent qualities. The quality category into which each needs item classifies can be determined by asking stakeholders two types of questions, positive and negative, for each needs item, as shown in Table 1. Each of the five response types is assigned a score from 1 to 5. In this example, the question asks about "(c) punctuality," and the respondent answers "very much yes: 5" to the positive question and "somewhat no: 2" to the negative question. After the interviews are completed for all stakeholders, the interview responses are aggregated and converted into the quality categories. While

**Table 1.** Question format for identifying quality categories.

| | Absolutely no: 1 | Somewhat no: 2 | Neither yes nor no: 3 | Somewhat yes: 4 | Very much yes: 5 |
|---|---|---|---|---|---|
| Would you like to introduce the TBM if it could "improve" the punctuality? (positive question) | | | | | ✓ |
| Would you like to introduce the TBM even if it "worsens" the punctuality? (negative question) | | ✓ | | | |

several methods have been proposed to convert the interview results into the quality categories, such as treating the results as discrete or continuous values [4], we used the following method to convert the interview results.

(i) The scores obtained from the interview responses are averaged for each stakeholder group according to the following equations.

$$\overline{p_{x,(y)}} = \frac{1}{N_x}\sum_{i=1}^{N_x} p_{x,(y),i} \tag{1}$$

$$\overline{n_{x,(y)}} = \frac{1}{N_x}\sum_{i=1}^{N_x} n_{x,(y),i} \tag{2}$$

$\bar{p}$ and $\bar{n}$ are the average interview responses with positive and negative forms. $N$ is the number of stakeholders to be aggregated. $p$ and $n$ denote the interview responses from each stakeholder with positive and negative forms, which can be one of the numbers from 1 to 5. The subscript $x$ indicates to which stakeholder group responded, which could be $pm$ for the policy making group, $ao$ for the ATC operation group, or $al$ for the airline group. The subscript $(y)$ indicates the needs item to which the interview responses were subject: the needs items (a) through (k). Thus, for example, $\overline{p_{ao,(g)}}$ means the average interview response with the positive form from the ATC operation group regarding the needs item (g). Then, $N_{ao}$ is equal to 4.

(ii) The interview results of the overall primary stakeholders were calculated as follows.

$$\overline{p_{all,(y)}} = \frac{1}{3}\left(\overline{p_{pm,(y)}} + \overline{p_{ao,(y)}} + \overline{p_{al,(y)}}\right) \tag{3}$$

$$\overline{n_{all,(y)}} = \frac{1}{3}\left(\overline{n_{pm,(y)}} + \overline{n_{ao,(y)}} + \overline{n_{al,(y)}}\right) \tag{4}$$

$\overline{p_{all,(y)}}$ and $\overline{n_{all,(y)}}$ are the average interview responses of the overall primary stakeholders with positive and negative form questions. To avoid the effect of differences in the number of stakeholders per group, $\overline{p_{all,(y)}}$ and $\overline{n_{all,(y)}}$ are not just the average of all stakeholders, but the average of each group.

(iii) Each group and the overall interview results are classified into the quality categories by referring to Figure 3. The dotted line means that the values on that line are not included. For example, when the positive value is 4.75 and the negative value is 1.5, the result is one-dimensional quality instead of attractive quality.

## 3. Results and discussion

### 3.1. Quality category

Table 2 shows the results of the quality categories for each needs item for each group and for the overall primary stakeholders. For each needs item, the results show that which needs items correspond to which quality category varies between the groups, while there are some similar trends among the groups.

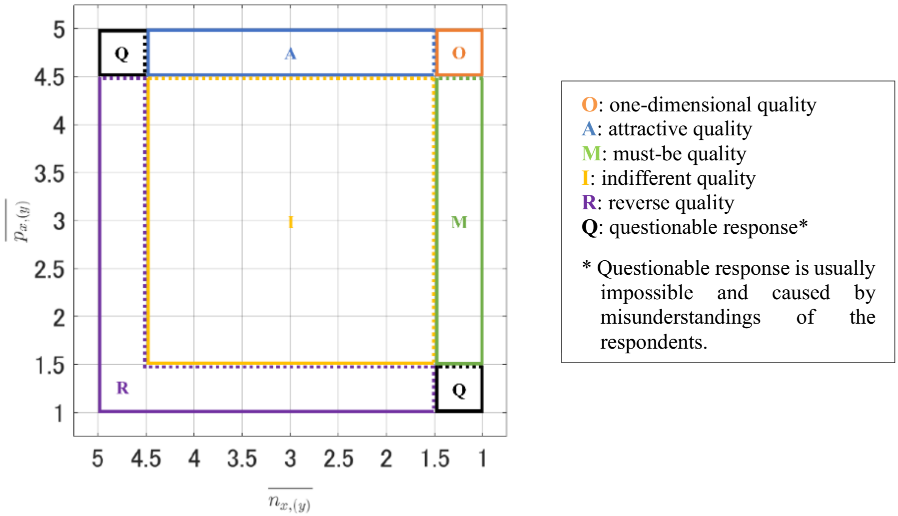


**Figure 3.** Classification thresholds for the quality categories.

**Table 2.** Results of quality category classification.

| | | Policy making group | ATC operation group | Airline group | Overall primary stakeholders |
|---|---|---|---|---|---|
| (a) | Time accuracy shared between the air and ground | O | O | M | O |
| (b) | ATC capacity | O | I | M | I |
| (c) | Punctuality | A | A | O | A |
| (d) | Fuel consumption and greenhouse gas emissions | O | A | O | O |
| (e) | Flexibility of choice for airspace users | A | I | O | I |
| (f) | Fairness among airspace users | A | O | O | O |
| (g) | ATC workload | A | O | I | A |
| (h) | Pilot workload | A | A | O | A |
| (i) | International interoperability | A | A | O | A |
| (j) | Continuity with current ATC operations and aircraft operations | I | I | A | I |
| (k) | Compatibility with current or planned ATC systems | A | I | A | I |

In the case of the overall primary stakeholders, the results showed that no need items were classified as the must-be quality which is the highest priority, and the needs items (a), (d), and (f) were classified as the one-dimensional quality which is the second priority. The needs item (a) is to improve the time accuracy of aircraft and ATC system trajectory predictions, a seemingly less obvious direct benefit to the stakeholders. However, in the past in Japan, an initial trial of the TBM component called calculated fix departure time, also known as calculated time over, caused some problems, due to the time accuracy discrepancy between the aircraft and the ATC system [5]. Therefore, it is assumed that all primary stakeholders considered the needs item (a) to be important in TBM, and as a result, it was classified as one-dimensional quality. Regarding the needs item (d), the term "flight shame" has appeared in recent years [6], and not only environmental engineering experts but also citizens are highly concerned about greenhouse gas emissions from air traffic. In this context, all primary stakeholders consider this item to be important. The policy making and ATC operation groups are responsible for the needs item (f), and the realization of this item would be beneficial to the airline group. It is assumed that the needs item (f) was classified as one-dimensional quality because it has a strong relationship with all three stakeholder groups.

The needs items (c), (g), (h), and (i) were categorized as the third most prioritized attractive quality. In this category, the differences in stakeholder positions were clearly expressed. The needs item (c) is widely used as a key performance indicator for airlines, and airlines are always highly interested in punctuality. As a result, only in the results of the airline group, the needs item (c) was classified as one-dimensional quality, while in the results of the other groups, it was classified as attractive quality. The needs items (g) and (h), workloads for the ATC operation and airline groups, were the one-dimensional quality for workloads on themselves, but were classified differently for workloads for others.

The needs items (b), (e), (j), and (k) were classified as indifferent quality. Both needs items (b) and (e) are important needs in air transportation, but the results of the overall primary stakeholder were classified as indifferent quality as a result of divergent opinions in each stakeholder group. On the other hand, the results of several stakeholder groups for needs items (j) and (k) were also of indifferent quality, so they can be considered to be classified as essentially of indifferent quality.

There were no needs items classified as reverse quality or questionable response.

### *3.2. Stakeholder value network*

The interview results identified which needs items were important to the primary stakeholders for ATC systems to realize TBM. Although the results do not directly reflect the needs of the secondary stakeholders, the priority needs items of secondary stakeholders can be estimated by referring to the SVN as shown in Figure 2. For example, the ATM support industry will receive money in exchange for the primary stakeholders purchasing ATC or flight management systems for TBM implementation. The airport community and adjacent ANSPs will receive more accurate flight information as a result of TBM implementation. Since these secondary stakeholders have the similar connections with all the primary stakeholders, it can be assumed that their needs match well with the needs of the overall primary stakeholders. On the other hand, since only the customer is connected only to the airspace users, it can be inferred that the customer's needs are similar to the airline group's needs only.

While the interviews were conducted only for the primary stakeholders, by designing ATC systems based on the quality category classification of each need item as shown in Table 2, it is expected that the realization of TBM will bring benefits not only to the primary stakeholders but also to secondary stakeholders, including ATM industry and airline customers.

## 4. Conclusion

This paper identified and analyzed the needs for TBM, which is one of the components of TBO. By creating the SVN, a stakeholder analysis was conducted and primary stakeholders regarding TBM were identified. Interviews were conducted with the primary stakeholders based on the Kano model, and TBM needs items were classified into five quality categories. The results of the quality category classification were analyzed, and the benefits to the secondary stakeholders as well as the primary stakeholders were discussed with reference to the SVN.

In future ATC system development, it is unlikely that the needs of all stakeholders can be fully satisfied for reasons such as cost, development time, technical issues, and their tradeoffs. However, if decision makers design ATC systems based on the results obtained from the needs analysis conducted in this paper, it is expected that TBM realized by the ATC systems can maximize the benefits for all stakeholders.

## Acknowledgment

The authors would like to thank the JCAB and the airlines for participating in the interviews. We would also like to thank the Aviation Technology Directorate of the Japan Aerospace Exploration Agency for helping to improve the interview format.

## References

[1] International Civil Aviation Organization, *Global TBO Concept*, Version 0.11, 2018.
[2] Federal Aviation Administration, *Trajectory Based Operations (TBO)*, https://www.faa.gov/air_traffic/technology/tbo (accessed on April 2024)
[3] N. Kano, N. Seraku, F. Takahashi, and S. Tsuji, Attractive Quality and Must-be Quality, *Quality*, 1984, vol. 14, no. 2, pp. 147–156.
[4] C. Berger, R. Blauth, D. Boger, C. Bolster, G. Burchill, W. DuMouchel, F. Pouliot, R. Richter, A. Rubinoff, D. Shen, M. Timko, and D. Walden, Kano's Methods for Understanding Customer-defined Quality, *Center for Quality Management Journal*, 1993, vol. 2, no. 4, pp. 3–36.
[5] D. Toratani, Y. Nakamura, and M. Oka, Data-driven Analysis for Calculated Time Over in Air Traffic Flow Management, *IEEE Access*, 2022, vol. 10, pp. 78983–78992.
[6] S. Gössling, A. Humpe, and T. Bausch, Does 'Flight Shame' Affect Social Norms? Changing Perspectives on the Desirability of Air Travel in Germany, *Journal of Cleaner Production*, 2020, vol. 266, 122015.