A Proposal for Capture and Allocation System for CO₂ Emissions to Cargo
～Toward a New Paradigm for Logistics and Consumption～

Tadayuki Masui†

Abstract
Global warming is a serious problem. As a signatory to the 1997 Kyoto protocol, Japan agreed to a 6% reduction of CO₂ emissions relative to 1990 levels. Since then, Japan has strived to achieve this target, but the recent situation in Japan is far from satisfactory; in fact an increase of 8% is predicted.

In order to keep its agreement, the Japanese government and many companies are continuing their hard work. In this paper, we focus on the logistics field. First, we report on and discuss the situation and some problems in Japan in this field relating to reducing environmental impact, especially CO₂ emissions.

In order to further reduce the CO₂ emissions, we propose a construction of a new paradigm that considers both economic and environment aspects and one that is acceptable to consumers. For this purpose, it is crucial to show the environmental impact, such as CO₂ emissions clearly and accurately. For example, the "carbon footprint" system is currently promoted in Japan and globally. However, the database is inadequate and the calculation methods for CO₂ emissions are no longer relevant right now. Therefore, an appropriate measurement method to obtain accurate data for CO₂ emissions is essential. In addition, a fair allocation system is even more essential. If possible, it is more desirable to adopt a calculation system for CO₂ emissions same as to "Activity Based Costing system".

In the logistics field, this problem is outstanding, the calculation and allocation of CO₂ caused by transport and/or delivery activities are made practically by the tonnage-kilometre (ton·km) method. In this paper, we focus on the logistics field. Logistics is a very important and basic field that relates to all companies, consumers and citizens in every society. As well as science and technology, a sociological approach should play an important part in reducing the environmental impact in this field.

First, we discuss the recent situation regarding environmental problems in logistics. Next, we arrange the efforts of the reduction of the environmental load by the government and companies. Thirdly, we propose a new paradigm for the logistics-consumption relationship. In order to actualize this paradigm, we then propose a new method for measuring CO₂ emissions by transportation and delivery activities and allocating them to each piece of cargo or owner of cargo. And by experiment, we show the validity of this system. Finally, we discuss directions in the near future and what the society should look like.

Key words: CO₂ emissions, truck transportation, load allocation, data capture system

1. Background
As well as improving our living conditions, customer’s demands are becoming more diverse. In order to improve the service level, the small lot and high-frequency deliveries are requested. Through development of information technology, it has becomes possible to order goods and settle accounts directly using the internet.

Computer technology makes our living conditions very convenient, but people cannot use the ordered goods without delivery or transportation processes. On the other hand, as the service level of delivery has become higher, the environmental problem has become more serious. This is the key how to design the physical distribution system as to satisfy both customer requests and the environmental aspects.†

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As many companies have begun to notice this situation, they have started to work on the logistics system. In conventional terms, it is generally accepted that the large-lot delivery or manufacturing is effective. Recently, however, due to increased diversity of customer’s requirements, it has become necessary to transport the required cargo, with the required volume, at required time, and to required place. As a result, the small-lot delivery systems have come to be regarded as normal, and today, the concept of “just-in-time delivery” has become an integral part of daily life.

On the other hand, many production and delivery processes consume huge amounts of energy and cause huge environmental impact. Figure 1 shows the volume of CO₂ emissions by each sector in Japan. The transport sector accounts for 20% of all emissions. In the industry sector, CO₂ emissions have flattened out owing to strong efforts. In the transportation sector, there was an increasing trend, but recently there has been a decreasing trend due to their efforts to reduce the environmental impact.

The social sector is important. We have to concentrate our attention on the fact that the consumer’s excessive requests or activities increase the CO₂ emissions.

Japan has tackled environmental problems as follows. In 1996, at the Kyoto conference, a logistics scheme was proclaimed and Japan made it clear to analyze their energies on its efficiency. After that, the Ministry of Economic, Trade and Industry of Japan requested information for logistics and started research on environmental logistics.[12,3]

In 2001, a new logistics scheme was determined, in this scheme, the need to enforce to the environmental problems was made clear.

In 2002, a “Manual for introducing the environmental logistics management system” was published. This is the list of the activities which are performed to reduce the environmental impacts in many companies, and additional activities which should be enforced in the near future. These activities are arranged in the checklist form. In 2003, a “the conference of environmental logistics” organized by many private enterprises was held with about 110 companies participating. The government and many organizations joined the conference as observers. From this, the “green logistics partnership party” was established by opening “the conference of environmental logistics” to about 3000 companies and organizations. These parties aim to tackle the environmental problems relating to logistics activity.

In 2005, the Kyoto Protocol came into effect by ratification of Russia. As mentioned above, Japan has been working to reduce environmental impacts, but there is little hope of achieving the targets for reductions. Recently, “Emissions trading” has been examined.

In this context, “the revised energy-saving law” was proclaimed in April 2006. Under this law, there is an obligation to reduce energy used in logistics activities. Notably, the owners of cargo, as well as the transportation companies are responsible for reporting a plan and result for reducing the CO₂ emissions by more 1% per year.

Transportation companies which have more than 200 trucks and owner companies whose transportation volume is more 30 million tonnage-kilometers per year are subject to this law.

The fact that the owner of cargo, along with the transportation company are subject to the law is very important. In 2009, the “Carbon foot print trial system” was enforced. This is a trial to involve consumers in activities aiming to reduce CO₂ emissions. This is an important concept in reducing energy used and global-warming gases. However in the present state of affairs, CO₂ emission data do not have sufficient reliability.

2. PURPOSE OF THIS PAPER

In this paper, we focus on the methods for measuring and allocating CO₂ emissions to each
piece of cargo transported by truck. The aim is to realize a new paradigm in which customers decide their purchasing cargo by referring to the environmental loads as the same as their prices.

For this purpose, we have developed a data capture system for CO₂ emissions data by using IC-tag technology. Aims of this system are to capture the CO₂ data in real-time and with high accuracy. Next, an allocation method is proposed based on these data. Using this system, a fair allocation of CO₂ emissions is also realized.

3. METHOD FOR CO₂ REDUCTION

3. 1 Classification of CO₂ Reduction Method

Activities for reducing CO₂ emissions can be divided into two categories: reduction of output and reduction of input.

Reduction of output refers to reducing the waste of materials for transportation packaging and reducing exhaust emissions. This category includes activities for CO₂ reductions.

Reduction of input refers to reducing the volume of the materials or energy used, such as cardboard or fuel.

Another aspect is the design of logistics system with considering the environmental impact. These are design of logistics system itself, design of environment-friendly goods and the environmental business transaction system, etc. Design concept is very important elements.

These are shown in Figure 2.

In addition, the most important issue is how to show the companies’ efforts to reduce environmental impact, such as reductions in CO₂ emissions, and how to design a social system incorporating consumers and business in which the environment impact of goods is regarded with as much importance as the price.

The main theme is to propose a new paradigm in which the customers decide what to purchase considering environmental impact and price equally.

3. 2 Activity Levels to Reduce the Environmental Impact of Logistics Processes

Next, we will discuss the reduction activities. Here we will focus on the activities related to make the social system rather than techniques. Many companies make many kinds of efforts to create a structure to reduce the environmental impact in the logistics fields.

There are various levels ranging from individual to society-wide activities.

We will mention the main activities according to their working range.

First are the activities which are promoted in each operation field. This category includes activities such as reducing the volume of many kinds of materials used for transportation, collection of garbage by type, eco-driving, and choosing the optimal delivery route.

Next are the activities organized in the physical distribution department. For example, reuse of containers and introduction of energy-saving vehicles etc.

More widely, there are activities incorporating many departments, for example, hanger transportation in cooperation with the sales division, and development of cargo which is easier to carry. Compact size detergent is a typical example of environmental cargo for transportation.

The next category includes the activities which are promoted through collaboration between many companies. This method enables the reuse of boxes, joint delivery or utilizing the truck on its return.

This collaboration by companies within the same industry makes it possible to standardize the container size or to adopt the milk-run delivery system in which materials or cargoes of many companies are gathered or delivered in the same truck.
Expanding this concept further, the collaboration between different kinds of industries makes it possible to establish a larger-scale joint distribution centre, for joint inventory management, or for shared information systems in order to implement effective distribution.

Additionally, the cooperation of the government makes it possible to establish a transportation hub and maintain the infrastructures; as a result, the modal-shift is promoted.

Finally, by collaborating among consumers and all of society, a new social system should be introduced such as eliminating surplus packaging, recovering packaging materials, and choosing suitable delivery lead-time.

To achieve these activities efficiently, the accurate data are required.

4. NECESSARY CONDITIONS FOR MEASURING CO₂

4.1 How to Measure the Effectiveness of Activities for Reducing Environmental Impact

Next, when executing these reduction activities, the problem is how to evaluate these results. First, it is important to grasp the problem connected to the environmental impact itself.

There are many difficulties associated with environmental problems in logistics because the point where environmental impact occurs varies. Therefore it becomes difficult to measure the environmental impact. Furthermore, there are many objectives in the system and they form a hierarchical structure. This leads to complexity.

First, how do we measure the environmental impact? Here we discuss this in relation to the transportation process. Theoretically, we should to measure the volume of CO₂ emitted directly by attaching the measurement equipment to the exhaust pipe. However, this method is impossible in terms of technical feasibility and cost. Nevertheless, we have to estimate the volume in some way. The best estimation is to multiply the fuel consumption by its CO₂ exhaust rate. However, there are many problems associated with this method as mentioned later.

The next problem is how environmental impact, such as CO₂ emissions, should be allocated. In logistics systems in which many objectives exist, this is a very difficult problem. Furthermore, the hierarchical structure makes it more difficult.

This issue is the following problem too. That is how to assign the beneficial results of reduction activities to related companies, when activities are promoted through collaboration with many companies. In such cases, it is important to determine a method which is satisfactory to all related companies.

This is a very important point because it relates to the values in the report for the CO₂ reduction plan and results for the revised energy-saving law. If the rule for allocating environmental impact is not fair, reduction activities will not be successful.

4.2 Methods for Determining the Volume of CO₂ Emissions of Transportation Activities

We will now discuss methods for determining CO₂ emissions. In the revised energy-saving law, the following three methods are recommended as methods to measure the energy used and CO₂ emissions in transportation processes.17

· [Fuel method] in which we grasp the fuel consumption data and the volume of CO₂ emissions is calculated based on fuel consumption.

· [Mileage method] in which we grasps the transportation kilometres and the volume of CO₂ emissions is calculated by multiplying it by mileage data. And the third,

· [tonnage-kilometre method] in which we grasps the transportation volume and distance, and the volume of CO₂ emissions is calculated by multiplying it by the CO₂ exhaust ratio. This concept of ton-km is usually used in the logistics field.

The [ton-km method] is very simple method and good for determining emissions macroscopically, but it has a very weak point. The following example demonstrates this weak point. We assume the situation in which 10 tons of cargo is transported 100 km. In this company, transportation was divided into two trips. After this, as an effort to improve efficiency, we assume that this cargo is transported in one trip. In this example, when we calculate the CO₂ emissions using the [ton-km method], the total ton-km is 10tons multiplied by 100 km which equals 1000 ton-km.

So, the CO₂ volume is calculated by multiplying this value by the CO₂ ratio of 0.178,
which produces the result of 178kg·CO$_2$. This result is same both before and after improvement. This is the problem of the [ton-km method].

For calculations using the [fuel method], before of improvement, the fuel consumption is 30 litres in the case of 50% load efficiency for each truck. Therefore, the total fuel consumption for two trucks equals 60litres, and the CO$_2$ exhaust volume is 157kg·CO$_2$.

After the improvement, the fuel consumption is approximately 37 litres with 100% load efficiency, so the volume of CO$_2$ emission is 97kg·CO$_2$. This method can reflect the improvement activities.

Figure 3 shows the relationship between the load rate and volume of CO$_2$ emission using the ton-km method. Using load-rate distinction, the volume of fuel consumption and CO$_2$ emissions are influenced strongly.

As mentioned above, the evaluation method is one of the very important points. However, it is difficult to grasp this fuel consumption data in the field. In reality in the field, usually fuel consumption for each trip can be determined at most.

The next problem is how to allocate the environmental impact to each piece of cargo. Generally, many kinds of cargo of different owners are loaded on the same truck. This is called “mixed delivery”. In this case, the problem occurs in how to allocate the fuel consumption or CO$_2$ emissions to each cargo or each owner.

Currently the allocations are made approximately after all transportation is finished using the ton-km method.

It is necessary to grasp the fuel consumption accurately and to allocate the CO$_2$ emissions to each cargo fairly in order to establish the new paradigm in which the customer chooses the cargo by considering the price and environmental impact.

5. CAPTURE AND ALLOCATION SYSTEM FOR CO$_2$ EMISSIONS

5.1 A Method for Capturing the Fuel Consumption Data in Real-time

The simple allocation method is one based on the weight of cargo and the transportation distance. However, in most of the cases in the actual fields, data as basic as the weight of cargo cannot be grasped. Furthermore, it is impossible to capture the data for load weights for each transportation sector because some cargo is loaded or unloaded on the way.

In the case of delivery, the results are different dependent on the delivery order. This is an important problem.

To cope with this problem, we have to develop an allocation method which is accepted by related owners. To cope with this problem, we propose a method of exchanging information between the transportation companies and owner companies.

We expect that advanced information technology and information network technology will support this.

5.2 Concept and Development of the Proposed System

In this paper, we propose a data capture and CO$_2$-allocation system. First of all, this is a kind of information system on the truck which keeps a record of delivery route, the amount of fuel consumption and calculates the CO$_2$ emissions in real-time using the fuel gauge and IC-tags. The fuel gauge and the information system is developed to measure the fuel consumption in real-time at each loading or unloading. For this objective, this system needs to clearly grasp the loading and unloading times and the cargo. Therefore, the read-write equipment and radio-frequency identification (RFID)-tags are used. A RFID system operating in the 2.45GHz band is employed from the viewpoint of usage condition and required specifications. The above systems are integrated. Using the captured information on the database, it is possible to allocate the CO$_2$ emissions to each piece of cargo.
by each transportation section in real-time based on the weight of cargoes. This is the most characteristic point of this system. Specifically, the difference of allocated CO₂ between the conventional and proposed method is clarified. We then give due consideration to the causes of the differences, in considering the transported weight, frequency of loading and unloading, and other system characteristics.

In order to clarify details of the proposed system, we demonstrate how to measure the transportation data for transportation companies and owner companies using the proposed system and evaluate the fairness of allocation of the CO₂ emissions. If the CO₂ emissions can be determined for each piece of cargo in all activities through the supply chain processes, we can show the total CO₂ emissions in all supply chain processes for each piece of cargo. As a result, the customer can select what to purchase based equally on the environmental impact and price. Consumers can choose the delivery method from the supplier, (for example, the route delivery or the direct sending), depending on environmental impact.

Furthermore, data on the volume of CO₂ emissions allocated for each pieces of cargo is useful from the viewpoints of both management of logistics activities and marketing strategies to get new customers.

5.3 "The RFID-tag Information System" to Obtain Data for Loaded/Unloaded cargo

In this system, the data of cargo loaded and unloaded are captured clearly using RFID-tags. A RFID-tag mounted on each piece of cargo, an antenna equipped on the hatch of the truck, and a reader/writer on the vehicle is prepared as shown in Fig.4.

Beforehand, information about the owner of the cargo and ID numbers of the cargo are written on the IC-tag by each. When cargo is loaded/unloaded, these data are read by the antenna automatically. Using this method, it is made possible to know the loading/unloading cargoes and their weights, and its time at the moment of loading/unloading actions. Practically, this is revolutionary in the actual fields. It is commonly the case that even the weights of cargo loaded is not known. Using this system, It is required by workers (truck drivers of the truck or delivery personnelers) can obtain data quickly, accurately and to get data without a lot of work in a short time.

Next, we examine two types of RFID systems; those operating in the 950MHz and 2.45GHz bands by the reason of characters of these. These IC-tags have the following advantageous characteristics. First, these can read and write data without actual contact. Second, multiple tags can be read/written through packaging. The appropriate frequency band should be chosen considering the communication range, accuracy and other conditions. Through practical experiments we found that many technical problems to be resolved remain. Therefore, realization of the proposed system is a not possible given the present state of affairs. However, the accuracy of the RFID-Tag system is expected to improve in the near future.

5.4 System Equipment Installed in the Vehicle

(1) RFID-tags

RFID-Tags are attached to on the goods themselves or each box and data of the cargo is recorded on this tag. The memory sizes should be selected according to the volume of data. It is necessary to select an appropriate tag based on...
the usage conditions such as surrounding shield, the noise, etc.

(2) RFID reader / writer and antenna (Fig.5)

One or more antenna is/are installed on the hatch of the truck and a reader/writer is installed inside the truck. As there are several frequency bands for the IC-tag system. It is necessary to select the best one appropriately according to the conditions of use. The number of antennas should be increased or decreased according to operating situation.

In order to send and receive data through the antenna efficiently, we set the output format and frequency of the measurement.

(3) Equipment installed in the vehicle for operation (Fig.6)

The database includes information regarding the loading of cargo and delivery, such as start/arrival time, loading/unloading points and volume of fuel consumption. These data are stored in the computer installed in the truck. In the experimentation phase, we use a laptop computer for operating and maintaining this system. However, in a utilitarian case it is supposed that this equipment should be incorporated into the fuel gauge in the future.

5.6 Fuel consumption data capture system

In this system, the transportation route is divided into some running-sections defined as

Fig.5 Necessary equipment as for one vehicle

Fig.6 User interface for driver

![Fig.5](image1)

![Fig.6](image2)

intervals between a stopping point and the next stopping point for loading and/or unloading the cargo.

The data of starting point is recorded. When the truck stops, its location, the fuel consumption (liters) between the start and stop points, and section distance (mileage:km) are recorded on the fuel gauge. This data collection is carried out continuously for each section in real-time (Fig.7).

At same time, CO2 emissions are calculated using an advanced fuel gauge. For this system, the existing advanced fuel gauge named "TRU-SUM" is introduced. We have developed and improved the TRU-SUM system to measure the fuel consumption in more detail for each section and in real-time.

Tab.1 List of initial information

<table>
<thead>
<tr>
<th>Label</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck Number</td>
<td>Identification number of truck</td>
</tr>
<tr>
<td>Sequence No.</td>
<td>Sequence No. for calculation</td>
</tr>
<tr>
<td>Time Stamp</td>
<td>&quot;yyyy / mm / dd / hh : mm : ss&quot;</td>
</tr>
<tr>
<td>Event No.</td>
<td>Classification number of each event (start/stop)</td>
</tr>
<tr>
<td>Latitude</td>
<td>Latitude (GPS) of loading/unloading point</td>
</tr>
<tr>
<td>Longitude</td>
<td>Longitude (GPS) of loading/unloading point</td>
</tr>
<tr>
<td>Deliverer ID</td>
<td>Deliverer (Driver)'s ID number</td>
</tr>
<tr>
<td>Mileage (km)</td>
<td>Accumulation Mileage delimited by event</td>
</tr>
<tr>
<td>Volume of Fuel Consumption</td>
<td>Accumulation fuel consumption delimited by event</td>
</tr>
<tr>
<td>Trip ID</td>
<td>ID number allocated each trip on delivery</td>
</tr>
<tr>
<td>Section ID</td>
<td>ID number allocated each section on trip</td>
</tr>
</tbody>
</table>
This system clearly distinguishes driving time or stopping-time through manual operation by the driver (or delivery personnel) (Fig.6). One of the future developments should be a function for the fuel gauge in which both times can be automatically distinguished and recorded. As an important function, this system calculates the CO₂ emissions for each section using the fuel consumption data. Furthermore, the resulting volume of CO₂ emissions is allocated to each piece of cargo in proportion to the weight of cargo, at the same time, and adding it to the previous volume of CO₂ emissions for the preceding section for each cargo. These data are written on the IC-tag on the cargo.

In this way, in all sections from the loading point to the unloading point of the cargo concerned, the total CO₂ emissions for its cargo is recorded on its IC-tag at the unloading time.

This system prepares the information table as Table-1. The travel information obtained from this table is as follows: Truck number, time stamp, and fuel consumption. This system clarifies the fuel consumption data
and driving status for the truck and enables the necessary information to be acquired in order to determine the CO\textsubscript{2} emissions of the owner.

Moreover, in the case of route delivery, it is expected that environmental impact allocated to the owners will change depending on the delivery route. Therefore, additional information processing should be considered for allocating the fuel consumption for each delivery method and contracts.

5.7 The Calculation and Allocation System of CO\textsubscript{2} Emissions for Each Cargo/Owners

Data related to fuel consumption, driving status, and loading/unloading of cargo using RFID-tags are connected via Ethernet communication.

In the proposed method, we allocate the volume of CO\textsubscript{2} emissions, which is grasped by the fuel gauge, to each piece of cargo. On the other hand, the cargo loaded on the truck in a certain section can be known. Using this information, it is possible to allocate CO\textsubscript{2} emissions fairly and in real-time.

Figure 8 shows the whole image of this system.

The allocation policy is based on the weight of cargo (see formulation (1)).

$$CO_{2i} = \sum_{j=\Phi_i} w_j \cdot CO_{2j}$$  \hspace{1cm} (1)

$CO_{2i}$: volume of allocated $CO_2$ emissions for cargo $i$ in the transportation section $j$

$CO_{2j}$: volume of $CO_2$ emissions for the transportation section $j$

$w_j$: weight of cargo $i$

$\Phi_j$: set of loaded cargo in transportation section $j$

Then the allocated emission volume of each section is cumulated. These volumes are cumulated for each piece of cargo by referring to the data base, and then updating the database. Finally, the total amount of allocated emissions (formulation (2)) is written on the IC-tag at the moment it is unloaded.

$$CO_{2i} = \sum_{j \in \Omega_i} CO_{2j}$$  \hspace{1cm} (2)

$\Omega_i$ = set of sections in which cargo $i$ is loaded on the truck

Constructing this system, it is possible to obtain data on the volume of CO\textsubscript{2} emissions and the cargo to be delivered in real time, as well as to determine the volume of CO\textsubscript{2} emissions for each piece of cargo.

6. EXPERIMENT of THIS SYSTEM

The effectiveness of the proposed system is examined by investigating the differences between the proposed and conventional methods. In this experimental simulation, we use a data set for driving, loading and unloading activities acquired from the real case of a transportation company.

In this case, many cargoes are loaded and unloaded at the various places required by multiple owners of the cargoes. In Table 2, the cargoes ID, loading and unloading points and weights of cargo are shown. Transportation routes and distances are shown in Fig 9 and Table 3.

<table>
<thead>
<tr>
<th>Tab.2</th>
<th>Transportation conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo's ID</td>
<td>Owner's ID</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
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<tr>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tab.3</th>
<th>Distance of each section (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
<td>distance</td>
</tr>
<tr>
<td>1</td>
<td>1.8</td>
</tr>
<tr>
<td>2</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td>2.4</td>
</tr>
<tr>
<td>4</td>
<td>4.8</td>
</tr>
<tr>
<td>5</td>
<td>0.6</td>
</tr>
<tr>
<td>6</td>
<td>5.4</td>
</tr>
</tbody>
</table>
Fig. 9  Truck route and loading cargos and unloading cargos

Tab. 4 Result of CO2 allocation to each cargo (compare with ton·km method)

<table>
<thead>
<tr>
<th>Owner's ID</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo's ID</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>Empty</td>
</tr>
<tr>
<td>Weight on cargo (kg)</td>
<td>47</td>
<td>31</td>
<td>34</td>
<td>13</td>
<td>25</td>
<td>37</td>
<td>41</td>
<td>57</td>
<td>70</td>
<td>106</td>
<td>0</td>
</tr>
<tr>
<td>Origin-Determination</td>
<td>0-3</td>
<td>1-4</td>
<td>2-6</td>
<td>2-8</td>
<td>4-6</td>
<td>5-10</td>
<td>6-10</td>
<td>6-8</td>
<td>6-9</td>
<td>7-9</td>
<td>10-0</td>
</tr>
<tr>
<td>Distance (km)</td>
<td>4.8</td>
<td>4.0</td>
<td>3.3</td>
<td>2.5</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>CO2 volume except for empty truck</td>
<td>9680</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The truck starts at Center (C) with cargo No.1, loads cargo No.2 at point 1, loads cargo No.3 and No.4 at point 2, unloads cargo No.1 at point 3, and so on.

At each point, ID numbers of cargo that are loaded/unloaded are read and recorded via the IC-tag system. During driving, the fuel consumption data are recorded via fuel gage in real time. At the stop point, the fuel consumption for that section is allocated to each

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cargo loaded in that section and added cumulatively. At the unloading point, the cumulative data are written on the IC-tag as the result for cargo.

Tab.4 shows the conditions of this simulation and the result of the CO₂ emissions obtained using the proposed system.

In this table, results of the allocated CO₂ emissions using the proposed method and the results by ton-km method, one of the well-known conventional method, are shown comparatively.

In this simulation, the calculations of CO₂ using the ton-km method are executed, using the fuel consumption data for each section.

However, practically, acquiring fuel consumption data by each section is not impossible. In other words, the values determined using ton-km method in this table are more accurate than in the actual field. In the actual field, fuel consumption data are grasped approximately by trip or month. Thus, the allocation is performed after the end of all transportation activities. Therefore, the results are more approximate than this result. Nonetheless, this result demonstrates that the allocated CO₂ emissions are quite different depending on the allocation method.

In Fig.10, the CO₂ emissions for each piece of cargo are shown relatively for each allocation method. The proposed method is the better in the sense that it reflects the actual transport activities. The fuel consumption is determined in detail for each section, and based on these data, CO₂ emissions are allocated correctly.

Consequently, the proposed method is necessary for measuring the fuel consumption and allocating it to each piece of cargo or owner.

7 Conclusion

In this paper we developed a real time capture and allocation system for CO₂ emissions of the truck transportation. Using this system, the amount of CO₂ emissions for each piece of cargo can be obtained.

Compared with the conventional ton-km method, the characteristics of this system make it possible to grasp data for each transportation section, transported cargo and owner of the cargos in real time and in detail.

These data on CO₂ emissions for each piece of cargo and each transport section, including data on cargo such as weight and volume, and data on sections such as distance, are fundamental to several purposes of logistics and business design.

However, there are some technological and systematic problems. The first is accuracy of reading and writing of the IC-tag equipment. We employed and examined the UHF band mode. In our experiment, some errors occurred such as the antenna missing a few IC-tags. Accordingly, there is a need to develop more accurate equipment.

Second is the problem of "justice". For example, in the case of route delivery the loaded cargo is different depending on the delivery route. As a result, a high percentage of the CO₂ emissions are allocated to cargo assigned to the last delivery point. In the reverse route, this cargo is unloaded at the first point, so the CO₂ emissions allocated are the lowest. For this reason, in the case of route delivery, CO₂ emissions should be allocated to each piece of cargo after gathering data of CO₂ emissions for all delivery sections. In this case, a plan is needed to allocate CO₂ emissions fairly to each piece of cargo or owners.

The third issue is the treatment of CO₂ emissions for the empty truck. Even during sections in which the truck is empty, fuel is
Which do you choice?

\[ \text{Price: ¥1500} \quad \text{CO}_2 \text{ emissions in Supply Chain} \]

\[ \text{Price: ¥1610} \quad \text{CO}_2 \text{ emissions in Supply Chain} \]

\[ \text{Price: ¥1600} \quad \text{CO}_2 \text{ emissions in Supply Chain} \]

**Fig.11** Purchase decision with considering price and CO2 emissions in supply chain[^10][^11]

consumed. Who should this CO2 be allocated to? In the ton-km method, it is assumed that the empty truck does not emit CO2, but this presumption is incorrect. In this paper, we assume that these emissions are allocated to the transportation company. This aspect needs further discussion.

After these problems are solved, this system is expected to become the basis for determining the CO2 emissions in the total supply chain.

As a result, the total amount of CO2 emissions will be shown quantitatively from the procurement process of materials to delivery of goods to customer, throughout many processes such as manufacturing, stock, transportation, sales, etc.

Using this information, customers will be able to choose goods by considering the environmental impact in the same way as price. This concept leads to a new sense of value and a structure which can become the main power for promoting a sustainable society.

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**References**


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