Complexity of rules in crowdsourced deliveries and its level of intrusiveness on participants: An experimental case study in the Netherlands

Xiao Lin[1], Yoshinari Nishiki[2], Lóránt A. Tavasszy[1]
Department of Transport & Planning, Delft University of Technology, The Netherlands
Technology of Future Utopia (TOFU)
Corresponding author: x.lin(a)tudelft.n1

Abstract: *Crowdsourced logistics systems are receiving increasing attention in both industry and academia. This paper takes a unique standpoint in studying the relations between overall system performance and intrusiveness to each individual's daily lives, by performing a case study in The Hague. Volunteering cyclists were asked to transport small parcels while simulating their daily commuting behavior. Movements of parcels were recorded by GPS trackers and later analyzed. The results show that a crowdsourced logistics system can balance the overall system performance and level of intrusiveness on each participant by having well designed organizing mechanisms.*
Keywords: *Physical Internet, self-organizing system, crowdsourced logistics, participant behavior, intrusiveness*

1 Introduction

With the developing technology and society's growing concern over environment, academic and industrial communities are rethinking the way we organize production, transportation, and logistics. Among the emerging conceptual solutions, crowdsourced delivery is receiving increasing attention. Crowdsourced delivery can be defined as a delivery service, a business mode that designates the outsourcing of logistics to a crowd, while achieving economic benefits for all parties involved (Devari et al. 2017).

The concept of crowdsourced logistics is related to the trend of sharing economy and Physical Internet (Rai et al. (2017), the idea that physical objects are transported in modular packets as efficient as possible to their destinations, regardless of the route followed). By making use of crowdsourced transportation capacities, deliveries of goods are done without having to deploy dedicated logistics services. This means a reduced delivery cost for the owners of products and decreased impact on the environment. In this context, items can be transported in a ``non-dedicated" context. These potential transportation capacities can be commuters, on which parcels ``hitchhike": imagine a situation when your neighbor brings your Amazon parcel to you, because he has happened to be at a location where your parcel has been placed.

Literature reports some pilot projects of crowdsourced deliveries. Rougès et al. (2014) analyze 26 businesses run by companies and start-ups that provide platforms for crowdsourced delivery. They point out that, with the framework of Physical Internet, the potential power of crowdsourced delivery could be one of the alternative transportation solutions. Furthermore, a multi-segment multi-carrier delivery mode called “TwedEx” is discussed in Hodson (2013): people carry packages secondary to their daily lives e.g., commuting. Each package is handled from person to person based on overlaps in time and space until the package is delivered. This business model is further researched in simulated numerical studies in Sadilek et al. (2013). The analysis shows great potential in this business model, as it has remarkable speed and coverage. The authors call for "constructing and fielding (such) services", which could provide new insights for crowdsourced activities and business models.

The performances of crowdsourced delivery systems have been analyzed in abundance at a system level. Chen et al. (2015) develop a method for recommending tasks to mobile crowdworkers with the aim of maximizing the expected total rewards collected by all agents. Soto Setzke et al. (2017) develop a matching algorithm that assigns items to drivers for delivery, with the objective of minimizing the additional travel time apart from planned routes. Chen et al. (2016) use Taxi data in a city as reference to develop a strategy to minimize package delivery time by assigning paths to each package request. Arslan et al. (2018) study a dynamic pickup and delivery problem in order to match the delivery requirements to existing traffic flow. These articles investigate crowdsourced delivery at a system level, mostly to optimize the overall performance of the system by improving matching or task assignments.

The aforementioned articles give no attention to individual participants in such a system. As mentioned in Hodson (2013), participants from the crowd are not dedicated employees of delivery companies, thus the delivery tasks are only a side-objective apart from their daily lives. Carrying a parcel and giving it to someone will for sure introduce some degree of disruption to their normal living patterns. Naturally, the more disruption the system imposes to each of the participants, the more likely it will affect the willingness of participant in a negative way. Understanding the degree of disruption will no doubt help design crowdsourced delivery platforms.

Limited research has explicitly discussed about the degree of disruption as well as the willingness of participation. Kim et al. (2018) introduce a "Hit-or-Wait" approach in order to balance the timing when participants are matched with tasks with minimal disruptions of their existing route. Chi et al. (2018) explore the motivations of participants in contributing to crowdsourced projects. They use the app Crowdsource from Google, which aims to acquire training data for machine learning projects. The result of their survey indicates that participants are eager to be recognized by an organization or a community, especially if the recognition can be globally known. Zheng and Chen (2017) investigate a crowdsourced task-assigning problem considering the possibility that participants may reject a task. They measure willingness of participation using probability of rejection. However, the practical meaning of this probability and how it can be derived from each participant remains unclear. Miller et al. (2017) study commuters' behavior by sending out surveys to understand how willing are people to participate as workers in crowdsourced logistics. Most of the relative research uses surveys or simulations, which are at a theoretical level.

In this paper, we use experimental case studies to investigate how crowdsourced transportation capacity can be best organized. We give attention to the relationship between the whole system and each individual. In particular, the link between effectiveness of system's overall performance and degree of disruption being brought to the participants. We define the likelihood that participating the crowdsourced activities disrupts a participant's daily lives as the *level of intrusiveness*. In order to observe this linkage, we conducted a case study in a small area in the Dutch city The Hague. Volunteers were invited to cycle in this area. Meanwhile, they were asked to form ad-hoc relays to deliver GPS-tracked mango parcels. In Section 2, we briefly look at the elements of self-organized, crowdsourced systems, and explain experiment design for the case study. In Section 3, the results of the experiments are analyzed. We also discuss the experiment results and the potential of this form of crowdsourced logistics. Section 4 concludes this article and points out future research directions.

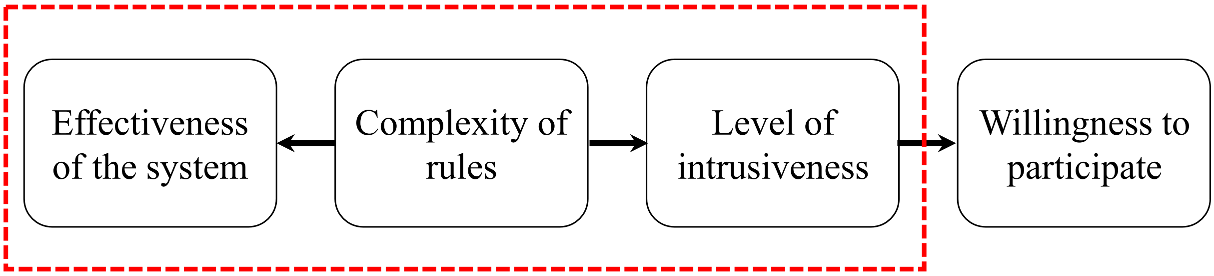

Figure 1: Relations regarding complexity of rules, level of intrusiveness and system design

2 Case study

In order to understand participants' thinking and behavior more effectively, this research uses experiments as case study. In the experiments, volunteers simulate commuting behavior on bicycles in an area in The Hague. Each volunteer follows his/her own route repeatedly. The volunteers are also asked to deliver packages of mangoes to specific locations. When they run into each other, they may pass on the packages until the mangoes arrive at the destination. The package is GPS tracked. Thus, we can observe how mango packages are transported in this area. This section starts with a brief overview of self-organizing logistics systems to motivate our design approach for the experiments.

A crowdsourced delivery system is also a self-organizing system. These bio-inspired systems, sometimes with high complexity, are based on entities that exhibit rather simple behaviors (Leitão et al. 2012, Bartholdi et al. 2010). An ant colony is a great example: each ant follows rather simple patterns of behavior, but can form a crowd that can carry out highly complex tasks. In the same way, to mimic such a self-organizing system, a well-defined set of rules is significant. Because the complexity of rules imposed on each individual is closely related to the effectiveness of the system, as well as the level of intrusiveness brought to each individual participant. A balance needs to be considered in designing a crowdsourced delivery system: the set of rules should be simple from each participant, but also able to facilitate a logistic system that is complex enough to accomplish its tasks in a practical and profitable way.

Fig.1 illustrates this trade off: more complex rules and tighter constraints lead to higher efficiency in achieving better performance at a system level; On the other hand, it may be highly disruptive, as we use the term "level of intrusiveness" to describe the tendency that following rules brings disruptions to participants daily lives. A higher level of intrusiveness will likely decrease the willingness of participants, for they need to go further to fulfill crowdsourced tasks. The experiment design in this study considers the complexity of rules and its impacts on both system level and individual level, to gain insight and give suggestions on designing crowdsourced logistics systems with a balance of system-wise effectiveness and level of intrusiveness on the participants.

We name our case study “Contingent Cycle Courier” (CCC) project. To best simulate the ad-hoc nature of the crowdsourced activities, the CCC project adopts a relay approach for parcel deliveries. In this approach, small-sized parcels are delivered to their destinations only by making use of accidental carrying power of cyclists in a city. Each parcel may "hitchhike" with several cyclists one after another, before it reaches its destination. In comparison with the traditional point-to-point (Arslan et al. 2018) and the lately discussed hub-and-spoke (Ballot et al. 2012) methods, this approach requires more collaboration among participants, and thus provides more room for them to take the initiative to make extra steps to ensure a task is successfully completed. This serves as indicators on how much intrusiveness a task brings to each individual.

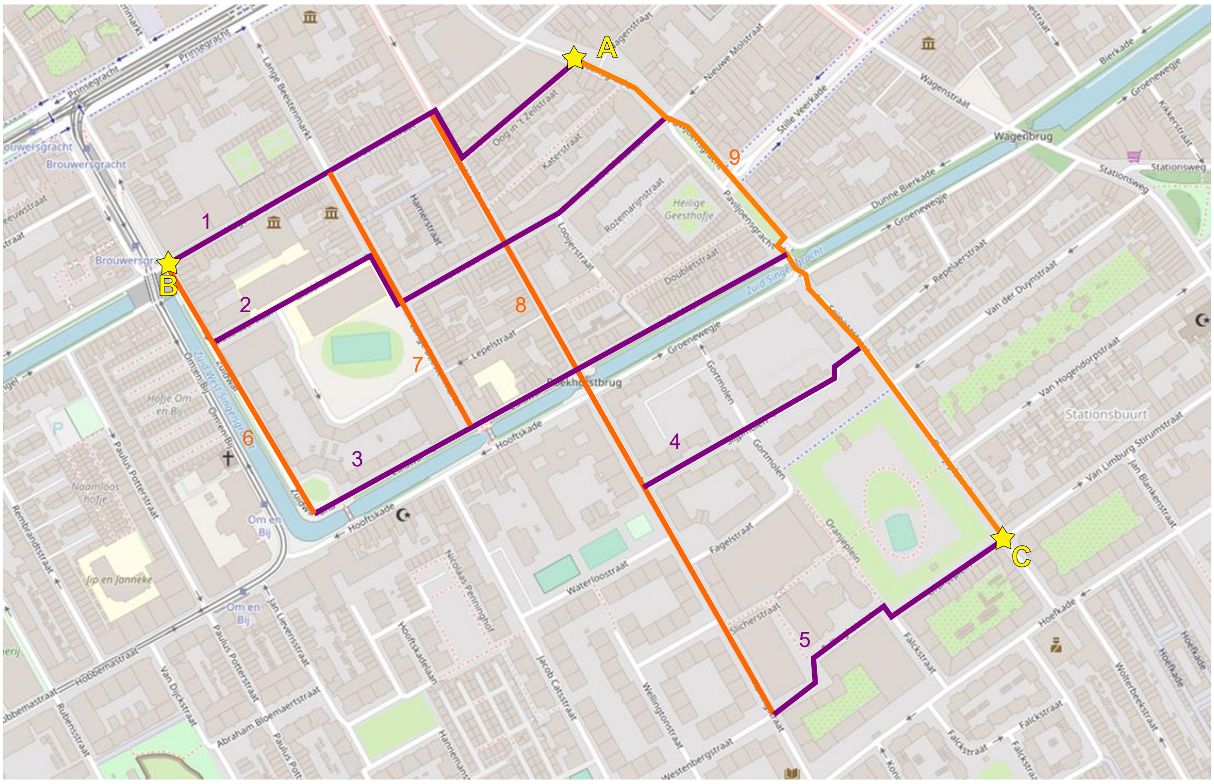

Figure 2: Selected routes numbered from 1 - 9. The map is derived from OpenStreetMap.

2.1 Route selection and parcel design

We invited 9 volunteers for parcel delivery. To simulate participants' different commuting routes, we chose an area in The Hague as shown in Fig.2. For each participant a route was selected and numbered from 1 - 9, and they traveled back-and-forth using bicycles along their designated routes. We took into consideration of the urban traffic and the safety of the participants. Some areas with complex traffic conditions were avoided. Before starting the experiments, the participants were gathered indoors to practice the activity using smaller scale simulations so that they became familiar with the rules.

For the CCC project, we designed parcels that are easy to be carried on bicycles. The small parcel was given a nick-name "Mango Equivalent Unit" (MEU). Fig.3 shows the design and actual size of an MEU.

At each of the points A, B, and C shown in Fig.2, a crew member was present to give out or to collect MEUs. Before each MEU was given out, a GPS tracker was placed, with the full awareness of each participants, to track the movements of mangoes. The tracking data is then used for analysis.

2.2 Scenario design

We designed 2 scenarios, each with a particular set of rules with different degrees of complexity. This was to observe the impact of complexity of rules on participants behaviors. Each scenario was experimented for 30 minutes.

Figure 3: Design of a "Mango Equivalent Unit" (MEU)

2.2.1 Scenario 1

In Scenario 1 the complexity of rules is lower. Cyclists follow the routes designated to them. When experiments start, parcels are handed over to Cyclist 1 and Cyclist 9 from point A. The cyclists can approach other cyclists they encounter when following within their own routes, to hand over a parcel. In the end, the parcels need to be delivered to point B or C.

2.2.2 Scenario 2

Scenario 2 has a higher degree of complexity on the set of rules in comparison with Scenario 1. In Scenario 2, MEUs are handed out at point B and point C. The ones from point B need to be delivered to point C, and the ones from point C needs to be delivered to point B. On each parcel there is a sticker with an icon and a color to denote the expected destination of this parcel, so that each cyclist should only pass the parcel to the right person to be able to complete the delivery. To ensure the deliveries are fulfilled, we design a grid system and relating rules to help the cyclists fulfill their tasks.

The grid system is applied to all cyclists on all routes as shown in Fig.4. Each of the cyclists is assigned to one of the two dimensions of the grid system, represented by icons or colors. Cyclists traveling along the dimensions wear hats to indicate their directions. The two directions are noted with the hats they put on. For cyclists traveling in the east-west dimension, they put on a red hat when traveling towards east, and put on a blue hat when traveling towards west. For cyclists traveling in north-south dimension, they put on a hat with a "tin" logo when traveling towards north, and put on a hat with a "flower" logo when traveling towards south. In this way, the point B on the map is denoted by a "tin" icon and the blue color, representing the north-west corner. Similarly, the point C in the south-east corner is denoted with flower and red.

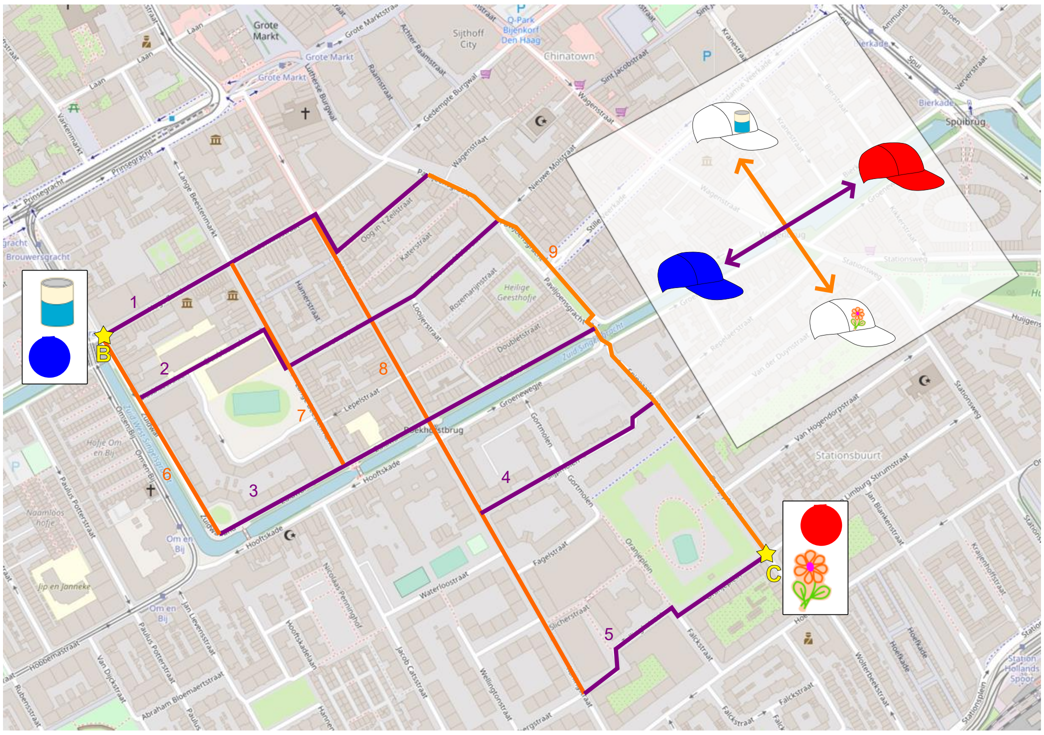

Figure 4: The routes and the grid system for delivering to specific locations. The map is derived from OpenStreetMap.

Half of the MEUs are handed out from point C, with a sticker of blue and tin denoting their destination at point B; and the other half start from point B and end at point C, which is denoted by red and flower. The cyclists carrying an MEU with the sticker blue tin, can only pass on the parcel to another cyclist with a blue hat or a hat with a tin icon. The cyclists carrying an MEU with red flower, can only pass on the parcel to another cyclist with a red hat, or a hat with a flower icon. By introducing these rules, each handing over is ensured to have the parcel one step closer to its destination.

We make a list in Tab.1 to compare the rules imposed on participants in 2 scenarios. In Scenario 1, the destination of a parcel can be Point B or C, thus only very basic rules are imposed to allow the parcels "flow" in the network. In Scenario 2, extra instructions are given to increase the efficiency of the system. Note that in both scenarios, the rules for each individual does not specify the overall objective of the system: to deliver parcels to specific points. Rather, the instructions to each individual are only to whom they can pass on the parcel. This design is in line with the principle of a self-organizing system, that simple rules imposed on each individual participant, can also achieve overall system-wise objectives that are more complex.

Table 1: Comparison of rules in Scenario 1 and Scenario 2.

	Scenario 1	Scenario 2
Follow given route	✓	✓
Receive and give out Parcels	✓	✓
Switch hats when turning around	×	✓
Read sticker on each MEU	×	✓
Give out parcels according to hats and stickers	×	✓

Figure 5: The route of a mango parcel in Scenario 1

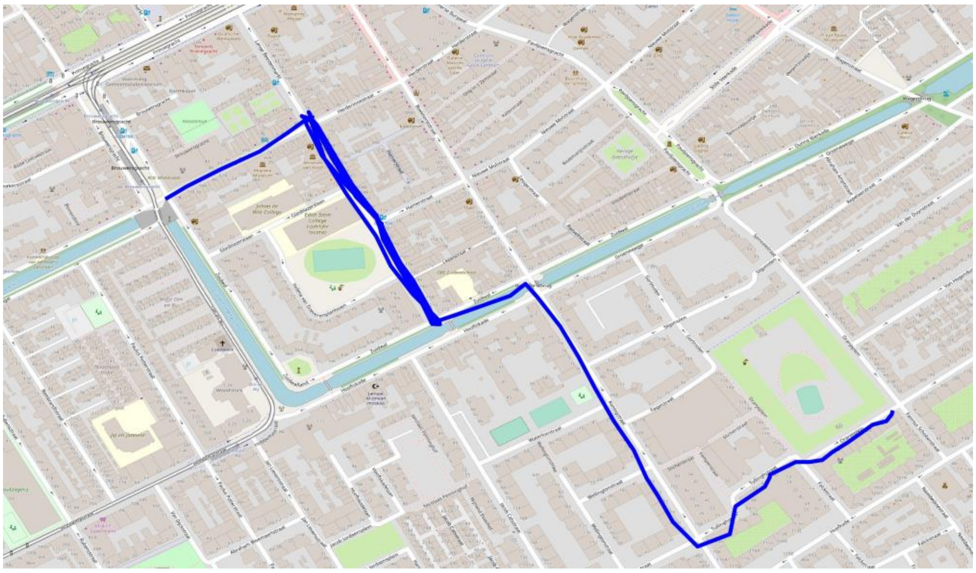

Figure 6: The route of a mango parcel in Scenario 2

3 Results and discussion

In this section, we discuss the results of the experiments by comparing the 2 scenarios. Fig.5 and Fig.6 show typical routes of a mango parcel in scenario 1 and 2, respectively. We do not directly compare the overall performance of the 2 scenarios (which are also not comparable since they have different objectives). Therefore, we choose several indicators that show the relation between the complexity of the rules, the level of intrusiveness, and how they could affect systems overall performance. This is discussed in the following parts.

3.1 Indicators

3.1.1 Pass

The number of passes denotes how many times each parcel hops from one cyclist to another. Note that when a mango carrying cyclist turns around at the end point of his journey and begins to travel backwards (with a cap switching motion), it also counts as one pass. This indicator gives an idea how long (and how complex) the journey was, before the parcel is delivered.

3.1.2 Long-wait

Each cyclist may choose to wait at an intersection to have the parcel handed over to someone else. (This was not specified in the rule but was not forbidden either.) If a cyclist waits for more than 30 seconds at an intersection in order to give the parcel away, this pass is counted as one long waiting pass. Note that when a mango carrying cyclist turns around without giving the mango to others, it also counts as one long waiting pass if he waits for more than 30 seconds at the turning point. This indicator helps us to understand to how much extend the cyclists are willing to act in align with the rules imposed on them.

3.1.3 Turn-around

We count the number of turning-around actions of mango carrying cyclists. If a cyclist turns around with a parcel, it means the mango travels longer distance than necessary to be successfully delivered, which could potentially lead to lower efficiency of the overall system. This gives us an idea on the effectiveness of the logistics system, in particular the efficiency of relaying activities.

3.1.4 Overlap

We count the total number of routes covered by each mango for more than once. This may also help us understand how much distance each mango travels over is non-effective, which directly relates to the effectiveness of the overall logistics system.

We list the data collected from our GPS trackers in Tab.2. The list comes in two sections: total count (which includes all parcels' movements) and successful delivery (which only includes movements of parcels that are successfully delivered within the given time).

Number of successful deliveries, average number of passes, long-waits, turns, and overlaps per delivery are shown in Tab.3.

Table 2: Data collected from the GPS trackers.

		Pass	LW	Turn	Overlap
Total Count	Exp 1	54	10	30	10
			18.5%	55.6%	18.5%
	Exp 2	72	25	27	11
			34.7%	37.5%	15.3%
Successful Delivery	Exp 1	42	8	22	5
			19.0%	52.4%	11.9%
	Exp 2	54	17	19	7
			31.5%	35.2%	13.0%

Table 3: Number of deliveries, average number of passes, long waits, turns, and overlaps per delivery.

	No. Delivery	Pass	LW	Turn	Overlap
Exp 1	7	6.00	1.14	3.14	0.71
Exp 2	11	4.91	1.55	1.73	0.64

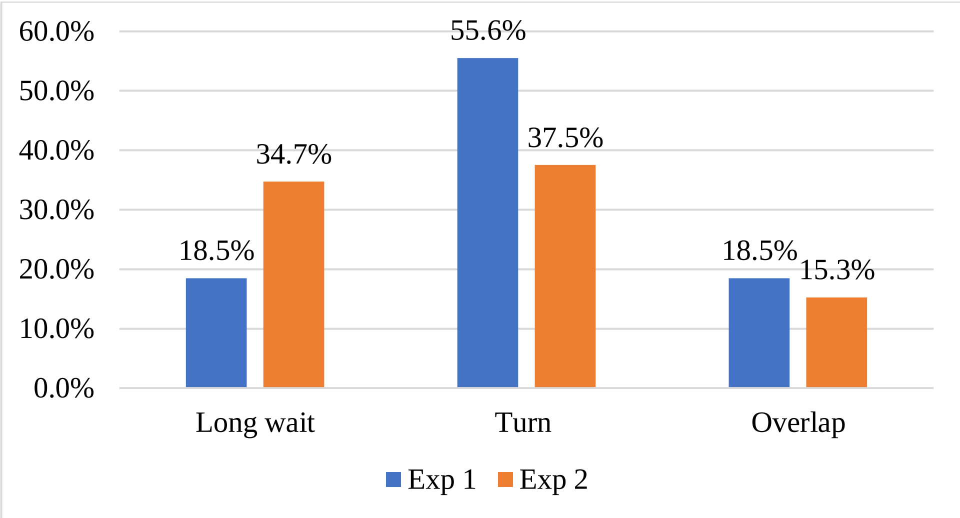

Figure 7: Long wait, turn, and overlap in percentage of all passes.

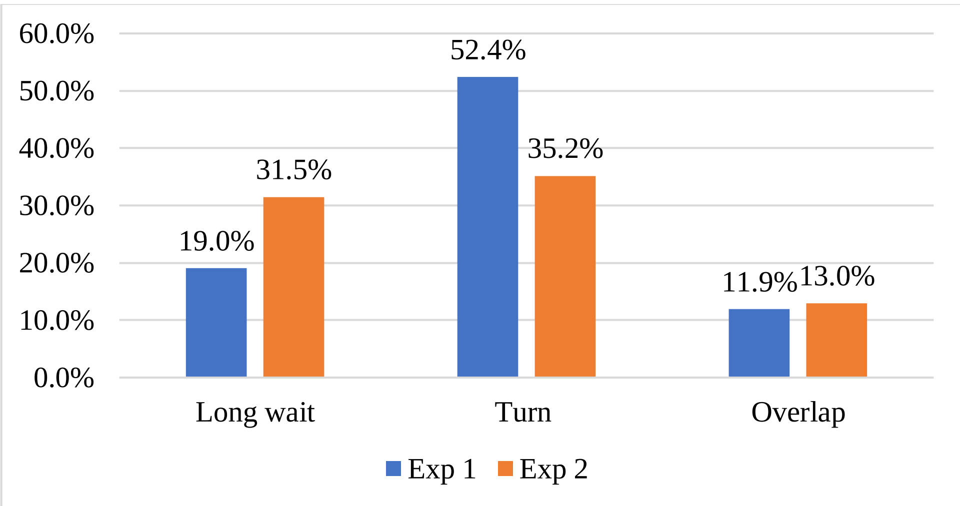

Figure 8: Long wait, turn, and overlap in percentage of passes contributing to successful deliveries.

3.2 Result findings and analysis

We do not compare the number of successful deliveries in two experiments, because this number is affected by the origin-destination arrangements. We only look into the motions of parcels to get an insight on behaviors of the participants.

More complex rules can contribute to better effectiveness. Fig.7 and Fig.8 show the percentage of long wait, turn, and overlap in all passes and in successful deliveries. In both figures, Scenario 2 has significantly lower percentage of turn-arounds among passes. This shows that less mangoes were traveling back and forth in the hands of the same participants, and that the relay of the parcels happened much faster. This is because in Scenario 2, the rules help participants identify the right person the parcel should be handed to. Thus, it decreases unnecessary trips. This shows that more complex set of rules can play a role in contributing to higher effectiveness of the whole system. This is also observed in Tab.3 in Scenario 1, each 6 passes lead to 1 successful delivery; while in Scenario 2, despite the stricter destination control rules, only 4.91 passes are needed to perform 1 successful delivery.

More complex rules bring higher intrusiveness. In both Fig.7 and Fig.8, Scenario 2 has significantly higher percentage in long waiting passes than Scenario 1 (by 87.6% and 65.8% in all passes and successful deliveries). This indicates that participants take more efforts to adjust their commuting activity in order to finish delivery tasks when rules are stricter in Scenario 2. In other words, as rules are more complex, the logistics activity becomes more demanding, and the participants react by putting more efforts to fulfill their tasks. This suggests that more complex set of rules brings higher intrusiveness to participants.

However, when rules become more complex, the increase of participants' efforts put into each *successful delivery* is less significant, as only 36.0% more long-waits per successful delivery is observed. This indicates that an increase of system performance does not necessarily require the level of intrusiveness to increase by an equivalent amount. This is especially notable for crowdsourced logistics system designers, as an effective design of the rules may increase system performance without having to raise too much the level of intrusiveness.

4 Conclusions

This paper uses an experimental case study to analyze the relations among system performance, complexity of rules and level of intrusiveness, in the organization of a crowdsourced logistics system. We recruited volunteers to participate in the case study, where they simulate their daily commuting actions on bicycles. In the meantime, we use their carrying capacity to move small parcels of mangoes and eventually deliver to certain locations. Each parcel was tracked by GPS trackers. The experiments were done in an area in The Hague, Netherlands. Results from the GPS were retrieved and analyzed.

From the analysis we can draw useful information regarding crowdsourced logistics systems. First, more complex rules bring higher level of intrusiveness. Thus participants, apart from their primary goals (i.e., their daily lives), may need to take extra steps, mentally and in practice, to follow the instructions given by the logistics system. Secondly, more complex rules may contribute to better overall system performance. In addition, our analysis indicates that when rules become more complex, the increase of effectiveness of the system may not be of the same amount with the increase of the level of intrusiveness. This is especially noteworthy, because it shows the significance of the design of rules of the crowdsourced systems: a well-designed system can accomplish much without being too intrusive and having to require more than necessary from participants. The study also provides reference from an economic perspective, as more intrusiveness could be paired with higher rewards, which keeps the logistics activity attractive to participants.

There are certain limitations of this study. Firstly, the experiments are only with 2 comparing groups, which makes it difficult to quantify the complexity of rules and the level of intrusiveness, which does not support deeper, more thorough quantitative studies. Subsequently, the participants in the experiments might see these tasks as their primary goal rather than the secondary, as the simulated commuting behavior is not their actual commuting behavior. Nevertheless, it does not diminish the value of this study, as it points out the importance of system design in crowdsourced logistics systems. It also reveals directions for further and more thorough study on crowdsourced logistics systems. In future research, it is worthwhile to conduct larger size experiments from people's real daily activities. It is also interesting to quantify level of intrusiveness, as in this paper, we only discuss it in a qualitative manner.

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