Self-organization in parcel distribution – SOLiD's first results

Hans Quak[1], Elisah van Kempen[1], Bernd van Dijk[2], Frank Phillipson[1]

1. TNO, The Hague, the Netherlands
2. PrimeVision, Delft, the Netherlands

Corresponding author: hans.quak@tno.nl

Abstract: *To bridge the gap between the long(er) term Physical Internet vision and the short term daily logistics operations, the Dutch Topsector Logistics (TKI Dinalog and NWO) requested a research project that would provide an impulse for self-organizing logistics. This contribution discusses the development of the research project SOLiD, Self-Organizing Logistics in Distribution, that answers to that request. First of all, we describe the design and developments of SOLiD by discussing the challenges in the parcel industry and how these could benefit from implementing solutions that relate to a more self-organizing logistics system. Next, the first results of SOLiD's experiments are presented. The experiments under consideration focus on dynamic planning and adding local intelligence to reduce handling activities. Lastly, we describe how autonomous sorting robots can be a means to achieve a more self-organizing logistics system. This paper provides new insights with respect to the considerations of designing, and the execution of practical experiments for implementing SOL as a step towards realizing the Physical Internet and make it more concrete for logistics industry.*

Keywords: *Physical Internet, Self-Organizing Logistics (SOL), Practical experiments, Parcel distribution, City Logistics*

1 Introduction

1.1 Towards a transition in the logistics system

Following Montreuil (2011) "the way physical objects are currently transported, handled, stored, realized, supplied, and used throughout the world is not sustainable economically, environmentally, and socially" and "Addressing this global unsustainability is a worldwide grand challenge, hereafter termed the global logistics sustainability grand challenge", we recognize the necessity for the logistics system to change in the (near) future. The grand challenge to make the transport and logistics system more sustainable is the major external driver for the required transition, as the Paris climate agreement requires a serious decrease in the GHG emissions of transport. Besides, transport turns out to be one of the most difficult and complex sectors to decarbonize.

Such a required transition could be seen as a major threat for the transport- and logistics industry in the coming years. However, the developed PI vision as well as other (external) developments, can also provide opportunities for transport- and logistics companies to, not only to improve the system's sustainability, but also to better serve the customers. The main contributing external developments we distinguish are:

- automation and robotization; and as a result a higher productivity level, which can make customer-oriented solutions affordable, that are currently (far) too expensive. The reduction in handling costs at different parts in logistics system (e.g. warehousing, last-mile deliveries) and the ability to run operations 24 hours a day could result in completely new logistics services satisfying customer demands better than the current services offered and at a reasonable price.
- full connectivity in the physical world; as the Internet of Things comes closer to reality, the digital and physical world integrate. This connected world allows physical objects, transport means and (logistics) infrastructure to be connected (constantly or intermittently). As a result new logistics services can be offered that are currently not feasible yet.

Although, these three developments, i.e. the requirement for more sustainability, automation and robotization, as well as the IoT-applications, are widely recognized to be or become very important to the logistics system in the future, for many logistics practitioners these developments sound more like the far future, than as concrete opportunities for their daily logistics operations. To bridge the gap between the long(er) term vision and the short term daily logistics operations, the Dutch Topsector Logistics (TKI Dinalog and NWO) therefore requested a research project that would provide an impulse for self-organizing logistics as well as a more concrete perspective / way of thinking for logistics practitioners with respect to opportunities for new logistics services or activities that on the short term can be expected by taking the mentioned developments in account. This contribution discusses the development of the research project SOLiD (Self-Organizing Logistics in Distribution) that answers to that request, as well as the first results of some of the experiments that followed that development.

1.2 Contribution's position and objective

This paper builds further on Quak et al. (2018) by discussing SOLiD's first experiments and how these can contribute to realizing some practical steps in the PI vision. SOLiD, (partly) financed by the Dutch Topsector Logistics (TKI Dinalog and NWO), started February 2018 as a response to the call 'Impulse for Self-organizing Logistics'. The nature of the call and the composition of our consortium[1] required us to satisfy several conditions for building up the project (for a more detailed account we refer to Quak et al., 2018):

- Enable research in an experimental environment,
- Proof-of concept project,
- The outcomes provide practitioners a perspective with respect to opportunities and barriers of a more self-organizing logistics system, and
- Experiments should be feasible on the short term and should fit in existing operations.

As a result SOLiD is composed around four different experiments in the parcel delivery industry. The experiments in SOLiD are a way to learn more on what self-organization could mean in daily logistics operations, rather than that the experiments are designed to develop innovations in itself. These experiments can provide an outlook with respect to the feasibility of a more self-organizing logistics system and the extent to which it possibly adds value for the parcel delivery- and logistics industry.

[1] The SOLiD project consortium consists of the following project members: TNO (project leader), DPD Netherlands, PrimeVision, TWTG, Thuiswinkel.org, the cities of Utrecht and Amersfoort and the Dutch universities: Delft University of Technology, Eindhoven University of Technology, Erasmus University Rotterdam and University of Groningen.

As this contribution continues on Quak et al. (2018), we also examined how SOLiD can be positioned in research published last year; when looking at the 2018 IPIC proceedings a few observations can be made:

- The papers take varying angles with respect the Physical Internet and the logistic system of the future. Some adopt a data-driven and technology perspective, amongst others: deep learning (Gijsbrechts & Boute, 2018; Hillerström et al., 2018), and blockchain (Hofman et al., 2018; Dalmolen et al., 2018).
- Relatively a lot of papers are conceptual in nature, but at the same time provide results of (small-scale) simulation studies. Though there is a wide array of topics among these, such as: inventory control models (Ektren et al., 2018; Nouiri et al., 2018), capacity of parcel lockers (Thompson et al., 2018) and order bundling (Ambra et al., 2018).
- Also papers can be categorized based on their primary focus on either hubs or networks in the PI.
    - Arjona et al. (2018) provide a framework for PI hubs based on hubs in the digital internet, Faugère et al. (2018) consider smart locker based access hubs, Wang et al. (2018) focus on smart design of the PI hub (or warehouse) itself, Buckley and Montreuil (2018) simulate the impact of modular containerization on a parcel logistics hub.
    - The more network focused papers amongst others discuss: a case-study on the possible outlook of the PI network in Hungary (Ehrentraut et al. 2018), a case study on bulky goods delivery (Luo et al., 2018), a case study of a PI test region in Austria (Brandtner et al., 2018; Haider et al., 2018), hyperconnected last-mile delivery of large items in urban areas (Kim et al., 2018) and intermodal route planning in the PI (Prandstetter (2018). More vision-like papers are amongst others on PI networks in general (Dong & Franklin, 2018), or more specific with the concept of LogiPipe as a logistics pipeline for last-mile distribution in the Physical Internet (Schönangerer & Tinello, 2018).

Based on the above analysis (in a nutshell) we can relate our work both to the more vision-like papers, as we provide an outlook for realizing PI through SOL (self-organizing logistics), and to the research that conducts simulations with respect to hubs, as we show the results of dynamic sorting at a parcel delivery hub (see this contribution's section 3). On top of that, we add by providing first insights in real-life experiments (see section 4) and examples of already piloted concepts, such as the connected and modular automated sorting solution (see section 5). By doing so, we aim to bridge the gap between theory and conceptualizations of the PI and real-life implementation and implications for logistics practitioners.

First, this contribution discusses the joint efforts of practitioners and researchers in the choices and development of SOLiD's experiments to examine what value SOL can have in practice in the parcel delivery industry. Subsequently it discusses the (intermediate) results of the practical experiments the authors are involved with:

- Experiment 1: Dynamic planning
- Experiment 2: Adding local intelligence
- Implementing autonomous robots in sorting process

Finally, in the concluding discussion it provides a direction towards a more self-organizing logistics system.

2 Experimenting with self-organizing logistics as step to realize PI

The necessity as well as the opportunities leading to a changing logistics system, as discussed in this paper's introduction are not new. A growing number of papers examines the possibilities and limitations of a more self-organizing logistics system, in which more autonomy at a decentralized level in the logistics system and more local intelligence can contribute to either performance improvements or a better way to satisfy increasing receivers' demands efficiency. Pan et al. (2017) describe the Physical Internet as an application of a Self-organizing Logistics System, in which physical assets, information systems and organization models are modularized and standardized to enable the connectivity, the following main functionalities are of importance in a future Self-organizing Logistics System:

- Openness (meaning that actors and assets can easily enter or leave the system).
- Intelligence (meaning the object-based capability of local real-time communication and activeness).
- Decentralised control (focusing on collaborative rules and communication protocols, that aim at preventing unexpected or undesirable system outcomes, rather than optimal planning).

Although, we mentioned developments in the introduction, that can lead towards the direction of a more self-organizing logistics system, such as the increase in connectivity, the further automation and the demand for a more sustainable logistics system, the transition of existing logistics systems is not evident for logistics practitioners, as was also recognized in literature by for example Sternberg and Norrman (2017) in a number of cautions for logistics practitioners in their PI review. Sternberg and Andersson (2014) do so with regard to decentralized intelligence in freight transport. They indicate in a critical review that - despite the growing number of studies and articles relating to decentralized intelligence in freight transport - there is little scientific support for the success of decentralized intelligence in logistics and that most research was mainly conceptual and rarely empirical. They conclude their review (of more than 40 articles) with the question if the transport efficiency can improve through more local intelligence. Next, Sternberg and Norrman (2017) discuss in their PI review (of 46 publications) that the majority of the PI literature contributions is conceptual. They conclude "What is crucial to understand from a shipper's or policy maker's perspective is that currently there are no well-developed models that illustrate how the move from the entrenched logistics models to the PI could ensue" (Sternberg and Norrman, 2017, page 750). Therefore, our aim is to experiment with logistics practitioners with only some of the functionalities Pan et al. (2017) mention for a self-organizing logistics system, as a full transition of the existing system is not within the abilities of (applied) researchers nor logistics participants in the short term. Our aim with these limited experimentations is to further develop both the thoughts in logistics industry on the (short-term) possibilities of more self-organization in logistics as an answer to existing and future challenges, as well as to enrich the scientific knowledge-base with more empirical evidence on applications where decentralized intelligence can be of value.

To reach this aim, we developed a research project together with logistics-practitioners (i.e. among others DPD Netherlands and Prime Vision[2]) and took their existing challenges as well as the expected future developments as a starting point to examine where some of the functionalities of a self-organizing logistics system could be applied and add value at the short-term. This has resulted in the research project called 'SOLiD'. In the remaining of section we shortly discuss the choices we made in the development of this research project,

[2] Prime Vision (PV) is a Delft based software company with a long history in Computer Vision – particularly Optical Character Recognition-, System Integration and Sorting Decision management. Today, the company focuses on broader AI (apart from Computer Vision, also Robotics, Machine Learning and Natural Language Programming), general decision management and data connectivity.

related to relevant literature. In the development of SOLiD we discussed several potential experiments that fit in the PI vision and in particular in applications of a more self-organizing logistics system for the parcel delivery industry. We choose the parcel delivery industry because of the following drivers that could allow for opportunities to develop new or other logistics systems:

- This industry faces – especially in the B2C home deliveries - an increasing development in customer-driven logistics, which can be a driver for a more self-organizing (decentral) logistic system, where web shops and carriers try to distinguish themselves by increased customer intimacy, and
- The volumes in this industry are increasing seriously.

Next, SOLiD's aim is not to develop a self-organizing logistics system for the parcel delivery industry, nor for one logistics operator, but to experiment with ideas that are in line with the PI-vision and can result in or show potential impacts of changes that could be undertaken to make the system more self-organizing. So the developed experiments in the project are not an objective in themselves, but a mean to further develop ideas and practical knowledge on the possibilities for a more self-organizing logistics system. Following Pan et al. (2017)'s functionalities of a future Self-organizing Logistics System, i.e. openness, intelligence, and decentralised control we developed several ideas based on the existing operations of our partner DPD Netherlands. In developing actual experiments we faced a couple of practical limitations. First of all, the functionality of openness is quite difficult to realize if you want to do experiments within running operations in a competitive market. We try to deal with this limitation by considering this functionality and its opportunities in the experiments, but do not actually combine or mix the existing operations of several (competing) parcel delivery companies. Next, practical limitations at the work floor or in the used systems can also be a limitation, as some functionalities are simply not yet available in most premises in the parcel distribution industry, e.g. parcels are not (yet) able to actively communicate. Based on such practical limitations, we developed a couple of ideas to gain (practical) knowledge in the possibilities and limitations for a more self-organizing logistics system in the parcel delivery industry.

2.1 Answering existing and future challenges in parcel distribution operations

First of all, there should be a logical reason to assume that a more self-organizing logistics system is an interesting direction for the parcel delivery industry. Therefore, we first examined the existing operations as well as the literature on what we defined most relevant and feasible as parts of a more self-organizing logistics system: more autonomy at a decentralized level in the logistics system and more local intelligence. We examined two areas where more self-organizing logistics elements could answer existing or future challenges in the parcel distribution system based on DPD Netherlands; i.e. i) challenges in the existing operations (also related to the increase in parcels over the last years and the expected growth) and ii) developments in the e-commerce and home-deliveries from the receivers and the e-tailers (i.e. customers of a parcel delivery company).

We started with examining the challenges in the current parcel delivery system of DPD Netherlands, and looked for solution-directions that would include more local autonomy or local intelligence. We also discussed challenges with two Dutch cities and the Dutch e-tailers interest organization Thuiswinkel.org. Based on the sessions with these organizations we found six challenges in the current parcel delivery practices, that (also on the short-term) could benefit from solutions that are (partly) in line with ideas to transform the system to a more self-organizing logistics system.

2.1.1 Relative static planning process

The existing process to determine the initial delivery areas in which the parcels are sorted at the depots are relatively static. The delivery areas are determined every four months and all parcels are already designed to a delivery area at the moment a label is printed by the sender of the parcel. After the sorting of the parcels in these fixed areas, the parcels have to be reshuffled to the right areas, depending on for example the exact number of parcels per delivery area, which takes extra time (and man-hours) in the sorting process. Making this static process more dynamically, would reduce the time and man-hours needed for sorting, and – in line with the SOL system – would also allow for openness in the future of such a hub. However, in order to do so, several issues should be dealt with. Practically, as humans do the last part of the sorting (in some depots), it should be clear in which delivery area they have to put the parcel. Currently, that information is printed on the label, but in case these delivery areas are dynamically assigned this would no longer be sufficient. This issue could be dealt with using local scanners that show the new delivery area. Next, there should also be ways to plan the areas more dynamically, including elements such as (expected or actual) volume and with that the total number of delivery areas per day, and requirements per delivery address or area (which can be considerably different for B2C and B2B deliveries – that are combined in the delivery areas). Although, this practice cannot be generalized to all parcel delivery companies, it shows that in practice openness of hubs is not straightforward. Not only are new dynamic planning processes and algorithms necessary, but the actual hardware in the existing system probably needs to be updated to actually execute these dynamic planning and sorting processes. The experiments and studies for this idea are examined in SOLiD's experiment 1 (see also section 3 for the first results).

2.1.2 Increasing receiver demands

One major future challenge, that could also be a driver for change in the home delivery industry, is the change in receiver demands. More and more flexibility is required at a late stage of the process. However, if all receivers get the opportunity to require last minute changes in e.g. time slots or even locations, it won't be possible to plan efficient delivery routes. Following among others McFarlane et al. (2016), adding local intelligence and / or more decentralized decision-making power at a system level will not necessarily lead to kilometer-efficient logistics, but it enables for better customer intimacy. McFarlane et al. (2016) indicate that especially intelligent logistics systems allow for a higher degree of receiver (customer) orientation, in which decentralized intelligence is required. In this way the logistics system is able to answer to developments as:

- individualization of customer demand (including further diversification in delivery options);
- more transparent planning and execution, and as a result the ability to communicate about deviations, whether or not due to external factors, such as varying from traffic jams, recipients not being at home for the package delivery, etc., and;
- further automation of more components within the logistics process, in which local intelligence of people will be replaced by more automated processes, which also raises the question, at which level which decisions should be taken autonomously and how to arrange the systems accordingly.

It is precisely in these cases that more decentralized intelligence (or decision-making powers) could lead to solutions, which may initially not be optimal (compared to centralized planning), but which can lead to a quick and reasonable solution within the reality that has arisen. And for these cases it might be interesting for logistics industry parties to make the first steps that are in line with a more self-organizing logistics system. We examine the possibilities and the effects of suchlike systems in SOLiD's case 3 (both in simulation, as well as in – still to be defined – experiments in some neighborhoods). However, at the moment case 3 is still under development and therefore no results can be discussed in the remainder of this paper.

2.1.3 Relative low hit-rate at certain times in B2C deliveries

Another existing challenge is that, especially in the B2C deliveries, the number of non-successful first time deliveries can be relatively high. In the case of DPD Netherlands, B2C and B2B deliveries are combined in one round trip, and most roundtrips are between about 9.00am and 6.00pm. Very often the parcel delivery company cannot communicate with the receiver (i.e. the customer of the shipper), as the shipper (i.e. the customer of the parcel delivery company) does not provide the receiver's communication details; usually for the second attempt, the receivers can contact the parcel delivery company and provide their delivery options, such as neighbor-delivery, put down at front door allowance, parcel shop delivery or specified delivery day (and time), which results in a high success rate for the second time deliveries. However, the hit-rate in the beginning of the afternoon is currently relatively low, as many receivers are not at home then and most B2B deliveries are made in the morning. Probably the simplest answer to this challenge is to start delivering B2C parcels in the evening, as more receivers are at home then. However, this is not really in line with the SOL system, nor is it desirable from DPD Netherlands perspective at the moment. Therefore, we aim at increasing the 'local intelligence', which means (as we cannot directly communicate with receivers, which would be the preferred option, see also 2.1.2) that we could plan to build address intelligence on neighborhoods where the first time right is relatively high and plan these parcels early in the roundtrips and the areas that have usually a low hit-rate later in the trips. These changes might influence the kilometer efficiency of the roundtrips, but that should be weigh up against the improved successful deliveries. SOLiD's experiment 3 deals partly with this challenge (see also section 2.1.2), however, we are – at the time of writing – still defining the exact experiment, so we cannot present results in this paper.

2.1.4 Expected increase in volume

A major challenge for parcel delivery companies is the yearly increase in parcels to be delivered, and in particular the increase in peaks; both in length (amount of days) and in height (the number of parcels on peak days). The main challenge lays in the capacity to sort all parcels for which more and more (expansive) sorting centers are necessary. Next, also the availability of delivery men and vehicles is a challenge for the peak periods. In section 5 we discuss an illustration of autonomous sorting robots (that can be self-organizing), as a way to deal with the sorting capacity in peak periods (which is developed by Prime Vision, separate from the SOLiD project).

2.1.5 Perceived van nuisance in neighborhoods

A complete different challenge comes from the participating cities. In many (Dutch) neighborhoods, residents (as well as other traffic participants) perceive nuisance from the many vans and small trucks making home deliveries. Although, ideas could be generated, such as neighborhood hubs (as part of the PI) to bundle all home deliveries for a neighborhood to reduce the number of vans from (competing) companies making home deliveries, experimenting with it in practice turned out to be quite difficult, as this would require the support and collaboration of more than one company making home deliveries.

Although cross-docking activities and activities at a parcel distribution center are not necessarily the same (as at cross-docking facilities some temporary less than 24h inventory might be held, whereas at a distribution hub parcels are immediately assigned to delivery areas), the study of Chargui et al. (2018) provides interesting results which might give us some insights with respect to Experiment 1 (see section 3) and the role of autonomous sorting robots (section 5). In the PI-hub the authors assume automated loading and unloading PI-docks and conveyors and an automated storage and retrieval system. Chargui et al. (2018) show that a PI-hub with automated loading and storage and retrieval have a positive impact on the performance of cross-docking facilities. Especially by reducing the waiting time of inbound and outbound trucks, the total time spent by products in the cross-dock and the number of inbound and outbound trucks waiting for a service. Similarly, our further work that will build on experiment 1 will look into KPIs such as waiting time and resource usage.

Another idea that was examined was the ‘self-organization’ of parcels in different vans, without the need for a local hub. The idea was relatively simple, two vans can park next to each other and based on parcel information exchange parcels so that the deliveries are smaller, and the number of vans necessary per area is halved. Unfortunately, the same barriers applied to this experiment as for the neighborhood hub, so this was not further developed. There are opportunities, though, for a reduction in vans by suchlike solutions, however this seems mainly interesting for neighborhoods and local policy makers, and business-wise not too interesting for the delivery companies at this moment.

2.1.6 Separation of tasks: efficiency gains for van driver / delivery person

Finally, we found another operational challenge; at the current operations at DPD the van driver loads its own van. The advantage is that the driver knows where the parcels are located in its van and the driver should be able to find the parcels relatively easy when delivering. The disadvantage is that it takes time from the driver, in which the driver cannot make deliveries. Considering the lack of drivers, as well as the (future) possibilities to partly automate this process (which would belong in section 2.2), we look at ways to add intelligence in the process, so that the driver can find the parcels in the van during the delivery route, also in case someone else loads the vans. SOLiD’s experiment 2 goes into this issue (which is described in more detail in section 4). From the direction of adding SOL elements in the process, this would contribute to adding more intelligence at a parcel level. In experiment 2 we focus on reducing the handling activities of the parcel before loading the vehicles in the parcel distribution hub. The throughput time of a parcel in a hub is critical to overall network performance. Similarly, Buckly and Montreuil (2018) also suggest to minimize a parcel’s required touches. However, their solution lies in introducing PI containers such as packs and boxes. These can ensure consolidation of parcels that head for the same destination. Simulated results show promising efficiency gains of 8% if parcels are pre-consolidated using these boxes. So there are different ways to reduce the number of handling of parcels and to improve efficiency. We were not able to include PI containers in SOLiD’s experiment.

2.2 Technology push: opportunities due to new technology

In our definition of directions towards more self-organizing logistics systems we considered more autonomy at a decentralized level in the logistics system and more local intelligence as most important elements. After examining the ‘pull-developments’ in the previous section that can pull the parcel distribution system towards a more self-organizing system, we also looked at ‘push-developments’. These push developments come more in the form of opportunities following from technologic developments that mainly allow for more automation in the parcel delivery system (see for example Maslarić et al. 2016).

Although some of the technology push developments can contribute to or closely relate to answering the challenges mentioned in section 2.1, the difference is that for the push category the main challenge is not so much in adding more autonomy at a decentralized level in the logistics system or more local intelligence. The challenge is mainly how to make sure that the existing local autonomy and intelligence that is available in the humans who are currently quite self-organized parts of the existing logistics system can be sufficiently made available in a more automated process. We recognize here that the automating of parts in the parcel distribution system in itself does not imply that the system becomes more self-organizing, but that for a more automated system the degree of local autonomy and intelligence are very relevant in the possibilities for the design. As a matter of fact, in the current system the humans turn out to be quite 'self-organizing' in solving issues and performing best practices based on experience. Therefore, we see quite a challenge in automating different processes, as that kind of behavior should be captured in order to make the parcel distribution system more autonomous (and the several elements self-organizing). We distinguished two ideas during the development of SOLiD that fall in the technology push category, i.e. autonomous sorting robots and the use of an autonomous moving locker box for make the last mile deliveries. The next sections shortly discuss these ideas. We are not able to realize these experiments in SOLiD.

2.2.1 Autonomous sorting robots

Montreuil et al. (2018) examine how hyper-connectivity and modularity concepts underpinning the Physical Internet enable the parcel logistics industry to efficiently and sustainably offer faster and more precise urban deliveries. In section 5 we provide an illustration that is precisely exploiting these two characteristics through implementing (modular) autonomous sorting robots in the parcel industry. This illustration is based on the developments by Prime Vision, and is not part of the SOLiD research project.

2.2.2 Autonomous parcel locker boxes for last mile deliveries

Finally, one technology push driver for more self-organization in the parcel distribution process that was often mentioned in the SOLiD's development stage had to do with automating the execution of the last mile, as this is both a relative expensive part of the parcel delivery system, as well as that it is expected to change in order to even deliver more receiver-oriented (see section 2.1.2). A possible technical solution would be to use autonomous vehicles for making the final deliveries. Some studies are showing the potential benefits (see for example McKinsey, 2018) and experiments are running (see for example the experiments with Starship's Self-Driving Delivery Robots), eventually we decided not the experiment in this direction in SOLiD. Although, we developed plans in which we could experiment with delivering via a driving parcel box, that would not have been autonomous in the neighborhoods but still use a driver, to examine the receivers' experiences, the expected time to real implementation of suchlike solutions (due to the too low TRL level of the autonomous driving vehicle) was the reason to focus on other elements that relate to a more self-organizing logistics system in the parcel distribution system.

2.3 Experiments and developments

Finally, we developed the plan for four experiments in SOLiD, that are often combinations of simulation studies, followed by experimentation in practice. SOLiD's four experiments are shortly mentioned in the previous sections and in Quak et al. (2018). The remainder of this contribution discusses the first simulation results of experiment 1 (more dynamically planning of the delivery areas) and the set-up of experiment 2 (adding local intelligence in order to reduce handling activities; i.e. separation of the van loading from the driver, but still provide the sufficient information to find the right parcels during the last mile delivery roundtrip). Experiments 3 (replanning of delivery routes based in receiver feedback – even during the trip) and experiment 4 (making local intelligence of a good-performing drivers available) are at the moment in the planning phase, and won't be discussed in the remainder of this contribution. This contribution discusses a side-development of PrimeVision that relates to the SOLiD experiments, i.e. autonomous sorting robots in section 5.

3 Experiment 1: Dynamic planning

3.1 Background and objective

In the current situation, the delivery areas at DPD Netherlands are already determined before the sorting process in the sorting center or hub location starts. The delivery areas are defined using historical data and are replanned every few months and are already printed on the labels at the moment of sending. As a result of this, fluctuations in the number of parcels in specific delivery areas can only be adjusted after the sorting has taken place. Reassignment of parcels to delivery areas is done manually after sorting in case some areas have too much or too little capacity left.

<u>Objective:</u> We aim to plan the delivery areas more dynamically. The question is how many parcel data is required to determine these areas better than is done in the current situation. By more dynamically planning delivery areas, this case provides a view on possibilities for decentralized sorting. These insights can be used in the parcel industry to handle peaks more easily by for example using small sorting robots. More flexibility in the planning is also a necessity in a SOL system for hubs to function, as the existing static planning way contradicts to Pan's et al. (2017) openness-functionality (as well to the other SOL system functionalities).

3.2 Method

In this experiment a simulation environment is set up where various dynamic planning options can be tested and examined in more detail. In essence we consider the issue of assigning the incoming parcels at a hub (with limited or no storage capacity) to a number of delivery areas. After the assignment to the delivery areas parcels will be distributed to the final receivers. An important challenge lies in the fact that the destination is not known on beforehand and is revealed only when it arrives at the hub. We distinguish two steps in our approach (Phillipson & De Koff, Working paper):

1. Initial assignment of the delivery areas: this gives a potential direction and scope of the delivery area.
2. Dynamic assignment of the arriving parcels: this involves the direct assignment of parcels that arrive at the hub. This occurs dynamically or 'on the go'.

For each of these steps we distinguish several methods. By combining these methods we can generate various possible scenarios, which we simulate in the simulation environment.

3.2.1 Initial assignment

The methods used for initial assignment are presented in Figure 1. In the first method (No load), the delivery areas (in Figure 1 represented as a van) stay empty until the first dynamic assignment in step 2 of the assignment process (see 3.2.2). The basic load method assumes that a certain percentage (x%) of the parcel's destination is known on beforehand. Subsequently these are assigned to the delivery

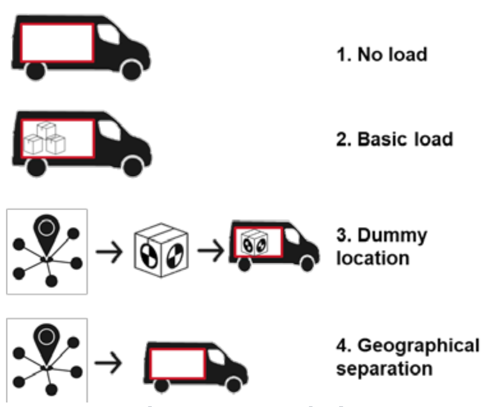

Figure 1 - Initial assignment method

areas using a VRP method solution. In case of method 3, separation by dummy location, a k-means clustering over all potential customers (based on postal code) is executed. Subsequently a dummy parcel with one of the customer cluster means is assigned to each of the delivery area. The fourth and final method also executes a (k-means) clustering over all potential customers. Then, a zip code cluster is assigned to a delivery area.

3.2.2 Dynamic assignment

The methods used for dynamic assignment are presented in Figure 2. The first method is based on smallest distance to cluster mean. The arriving parcel is assigned to that delivery area for which the distance from the parcel destination to the geographical mean is minimal. In case of dynamic assignment based on minimal insertion costs we calculate a minimal cost of inserting the arriving parcel destination to the route of a specific delivery area. The insertion that is cheapest will be selected. The third method uses fixed clusters; the parcel is assigned to the cluster it belongs to using the postal code of the receiver. The fourth strategy is proposed to account for situations in which parcels arrive at the hub that should have been assigned to a vehicle, but cannot, due to capacity restrictions. The price of insertion increases when the vehicle has more load.

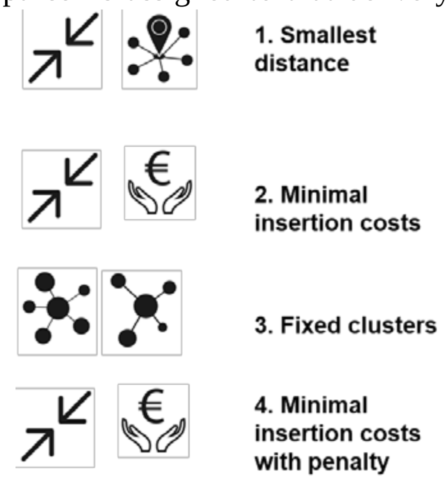

Figure 2 - Dynamic assignment methods

3.2.3 Assumptions

The assumptions made in this simulation are listed below:

- Demand = parcels have to be delivered to receivers in a certain region
- There is a homogeneous demand over all potential receivers. Receivers are characterized by a postal code area.
- In the base case the parcel is simultaneously with revealing its destination assigned to a delivery area (and an outgoing vehicle).
- The delivery areas (and vehicles) have a fixed capacity, implying that: in case of dynamic assignment method 1 and 2, the vehicle cannot be selected anymore for assignment if the vehicle is full.

3.3 Result

Various scenarios (a combination of an initial assignment method and a dynamic assignment method) were tested and compared a 'full information solution' in which all information (amount of parcels and related destination) is known on beforehand. Phillipson and De Koff (Working paper) show that the best performing methods are: A). The combination of No load (1) and dynamic assignment by minimal insertion costs with penalty (4) and B). The combination of separation by dummy location (3) and dynamic assignment by minimal insertion costs with penalty (4). These two methods would result in a 14-17% higher cost than the full information VRP solution.

Further analysis reveals that forecasting can be very powerful. In this scenario there is a known basic load for all delivery areas and dynamic assignment using 'minimal insertion costs with penalty' is used. Furthermore, 50% of the destinations of parcels is known/ forecasted on beforehand. Consequently, a decrease in costs can be realized and this solution results in a 6% higher cost than the full information VRP solution. To conclude, a dynamic assignment method that minimizes insertion costs whereby insertion prices increase when a vehicle has more load, leads to most favorable results in terms of costs minimization. The outcome can even be improved if the destination of half of the parcels is forecasted.

3.4 Experiment 1 in relation to SOL

The situation continues coming period, where we also examine if adding of more information (e.g. parts of the incoming parcels is pre-registered) can help in making forecasts in both the expected volume for a day and the expected distribution – including also historical data on volumes. At the same moment, the necessary hardware changes are also made by DPD Netherlands, which make it possible to actually execute a more dynamic planning of delivery areas; i.e. the information on the final delivery area should be made available to the final sorter (also there where this is done manually, and where people now rely on the printed area on the label). This continuing study and experiment shows, that it now already has advantages to move more in the direction of what would be necessary in hubs in a self-organizing logistics system. This enables current operations to become more efficient, and at the same time provides the first (small) step to become aware and a bit ready for the logistics operator for the transition towards a more SOL system in the parcel industry (in the future).

4 Experiment 2: Adding local intelligence to reduce handling activities

4.1 Background and objective

In the current situation after parcel sorting several manual actions are required by the van driver. Such as reassigning parcels to delivery areas in case capacity requirements are not met. This is a highly unfavorable situation as drivers bring more value to the parcel distribution system when they are actually driving around and distributing parcels, instead of manual actions inside the distribution hub to cope with and solve inefficiencies that result from the sorting process. One of the tasks that could be separated from driving and delivering is the loading of the vans. Currently the driver is loading the vans, which has the advantage that the driver already saw all parcels and knows where the parcels are in the van when starting the roundtrip. Note that the amount of parcels is high, and that the vans are relatively fully loaded (which makes the use racks, as is common-practice at some express distributors, in the van impossible, as this would reduce capacity too much).

Objective: We aim to reduce handling activities. It is hypothesized that once handling becomes more efficient, self-organizing logistics can be realized sooner; parcels ‘flowing’ through the system will become a closer reality. In order to reduce handling activities it is chosen to add local intelligence in the process.

4.2 Method

In this experiment we compare a more central form versus a more decentral from of intelligence. We do so by developing two elements. We include local intelligence by adding a location of the package in the van in the hand-held of the driver: by means of a virtual grid in the van, the parcels are indicated where in the van the specific parcel must be placed during the loading This location is made available to the driver during the execution of the trips. This decentralized intelligence is further increased as photographs (made during the sorting process, i.e. on the sorting belt of each package, are also made available to the van driver. The barcode of each package is linked to the relevant photo and location in the van. Next, the van driver is enabled through an interface (e.g. a smartphone) to view the picture of the package and the location (where it was placed during the loading of the van) on the mobile phone. The duration (and thus performance indicator "costs") to find the right package in the delivery van is measured (and compared to the first situation). At this moment, the technical developments are finished, so that both the locations in the van are assigned (and if necessary overruled by the person loading the van) and the pictures are taken during the sorting. This information is now linked to the information the driver normally has, such as bar code and address.

The first measurement for the experiment are also done; which basically only includes measuring the time it takes to load a van by an experienced van driver. Next, the experiment continues, at this moment it is planned both in a controlled environment (loading and unloading of a fixed set of parcels by a test person) and in the practice (with experience drivers doing the unloading during the roundtrip).

4.3 Experiment 2 in relation to SOL

Both ways to add local information in the parcel delivery process provides ways to disconnect the loading of the van from the unloading of it during the execution of the actual roundtrip. This shows how parts of the process could be further automated (i.e. technology push, in which case it is necessary to increase the amount of local information, as some of the self-organizing elements of the human being who is responsible for the process at the moment, is nreplaced due to automation). Besides, it also illustrates how, in a more self-organized (like PI application) situation, van drivers can easily distinguish the right parcel – even if it comes from other networks and is not loaded by the driver.

5 Autonomous sorting robots as a means towards SOL.

As described by Quak et al. (2018) external developments such as the progress and increasing pace of automation and digitization enable the connection between the physical and the digital world. These create ample of possibilities for a transition of the logistics system into a more self-organizing system. We do not argue that automation and digitization automatically would lead to a self-organizing logistics system, nor that all logistics systems should become more self-organizing. Rather, we see some direct examples in how automation can contribute to self-organizing logistics. As such, we explore the possibilities of the Autonomous Sorting System that PrimeVision, a SOLiD project partner, is experimenting with.

5.1 Autonomous sorting system – the concept

PrimeVision introduced the Rover, an autonomous robot, controlled via algorithms, that can identify, assess, sort and physically transport items to dispatch location (see Figure 3). Currently pilot implementations at logistics companies are running that combine the Rovers with human operators. The operators scan the parcels and put these one-by-one on the Rover (Figure 4). The Rover automatically determines to which destination conveyor belt the parcel should be transported and makes sure it arrives there. The Rover drops the parcel at the destination conveyor belt and finally the operator takes the parcel off. Rovers are safe to operate alongside human co-workers.

Figure 3 - Rover: An Autonomous Sorting Robot by PrimeVision

1. The operator scans the parcel and puts it on the Rover | 2. The Rover finds its way | 3. The Rover drops the parcel at the destination conveyor belt | 4. The operator takes the parcel from the roller belt.

Figure 4 - Autonomous sorting system as example of a self-organizing logistics solution (source: PrimeVision)

5.2 Developing autonomous sorting

Postal and logistics companies are keen to learn how intelligent combination of advanced robotics and Internet of Things (IoT) could bring cost and efficiency savings to the parcel sorting processes. To meet this demand in the logistics market, the Autonomous Sorting Robots were invented and developed. The Rovers are not a stand-alone technical innovation, but are part of a broader vision that impacts the whole (parcel distribution) logistics system (see figure 5).

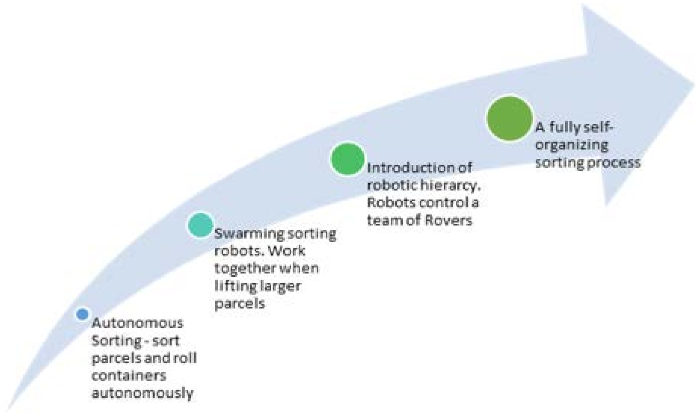

Figure 5 - From autonomous sorting robots to a fully self-organizing sorting process

Autonomous robots: To date the robots autonomously sort parcels and are able to roll containers. Currently, the system is organized in a hybrid fleet management system. The robots operate in a decentral path, while decisions are formed with information from a central database. The configuration of the current robots was created in close cooperation with technical partners and also insights gained through market consultation were incorporated. The design is adapted to meet Working Conditions regulations. Computing power has been increased to allow for higher quality algorithms and sensors. Also, further autonomy has been achieved by decentralising collision avoidance, path planning and navigation.

Swarming robots and robotic hierarchy: The next step in the development of the Rovers is to create the ability for the robots to swarm. The robots work individually, but can work together as a single unit to move larger items when needed. The Rovers will be designed to behavior similar to worker bees, collision evasion is inbuilt, allowing them to work together when lifting larger parcels. Furthermore it is planned to introduce a robotic hierarchy, with a master-slave relationship that employs increased intelligent robots that able to make real-time, data-led decisions to control teams of Rovers.

A Self-Organizing Sorting Process: Eventually the swarming autonomous sorting robots can be part of a more broadly self-organizing sorting process, whereby also robotic loading arms, autonomous vehicles and maybe even drones can be deployed. It is important to note that the ultimate goal is *not* to automate the current system. Rather, the cornerstones of the envisioned self-organizing sorting process are agility and scalability. PrimeVision closely monitors the responses in the logistics practice towards their autonomous sorting system. It is observed that practitioners in the logistics industry value the flexibility and the modularity of the system. It is exactly these characteristics that make it fit in the Physical Internet vision. As figure 5 also illustrates, suchlike – at this moment – small new innovations in the system can be a starting point for a larger transition of the system towards a more self-organizing parcel delivery system.

6 Concluding discussion

This contribution deals with the first results of the SOLiD project; Self-Organizing Logistics in Distribution. Already described by Quak et al. (2018) how serious gaming and practical experiments can contribute to raise awareness for realizing the PI vision, we build further on this by providing the latest findings in SOLiD on dynamic planning approaches and adding local intelligence for reducing handling activities. Also we describe – though not in the scope of SOLiD, but executed by one of our project partners – how autonomous sorting robots can be a means for achieving a more self-organizing logistics system. As this paper presents SOLiD's (preliminary) results of experiment 1 and 2, future contributions will further deepen these and look into whether and how to implement these in daily operational business. Also next year, results of SOLiD's other experiments on continuous replanning of delivery routes based on receiver feedback and local intelligence of good-performing drivers can be expected. By that we will give a more practical contribution to the field of Physical Internet and Self-Organizing Logistics in the parcel distribution industry.

By showing the process of designing and developing real-life experiments towards a more self-organizing logistics system as a step to the Physical Internet, we hope to inspire other researchers in the field of PI as well. By analyzing the current logistics system (which is in our case limited to the parcel distribution industry), identifying challenges together with logistics industry and related stakeholders, coming up with self-organizing logistics solutions that might help overcoming or bringing benefit to these, and translating these into concrete experiments, we have shown a way of bridging the gap between the more long(er) term PI vision and short(er) term implications for logistics practitioners. Here we would like to emphasize the importance of this process as we believe that the field of PI could move forward by more practical-based research with a clear perspective for action for the logistics industry.

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