

LaDe: The First Comprehensive Last-mile Delivery Dataset from Industry

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Abstract

Real-world last-mile delivery datasets are crucial for research in logistics, supply chain management, and spatio-temporal data mining. Despite a plethora of algorithms developed to date, no widely accepted, publicly available last-mile delivery dataset exists to support research in this field. In this paper, we introduce LaDe, the first publicly available last-mile delivery dataset with millions of packages from the industry. LaDe has three unique characteristics: (1) *Large-scale*. It involves 10,677k packages of 21k couriers over 6 months of real-world operation. (2) *Comprehensive information*. It offers original package information, such as its location and time requirements, as well as task-event information, which records when and where the courier is while events such as task-accept and task-finish events happen. (3) *Diversity*. The dataset includes data from various scenarios, including package pick-up and delivery, and from multiple cities, each with its unique spatio-temporal patterns due to their distinct characteristics such as populations. We verify LaDe on three tasks by running several classical baseline models per task. We believe that the large-scale, comprehensive, diverse feature of LaDe can offer unparalleled opportunities to researchers in the supply chain community, data mining community, and beyond. The dataset homepage is publicly available at <https://huggingface.co/datasets/Cainiao-AI/LaDe>.

1 Introduction

Driven by increasing urbanization and e-commerce development, last-mile delivery has emerged as a critical research area with growing interest from scholars and practitioners. **Last-Mile Delivery**, as illustrated in Figure 1, is the package transport process that connects the depot and the customers, including both the package pick-up [1, 2] and delivery [3, 4] process. In addition to being a key to customer satisfaction, last-mile delivery is both the most expensive and time-consuming part of the shipping process [5, 6]. Consequently, researchers from different fields, from logistics operation management to spatio-temporal data mining, have been consistently shedding light on problems in last-mile delivery in recent years. These problems include route planning [7, 8, 9], Estimated Time of Arrival (ETA) prediction [10, 11, 12], and route prediction [13, 14, 15], etc. A quick search for “last-mile delivery” on Google Scholar returns over 19,400 papers since 2018.

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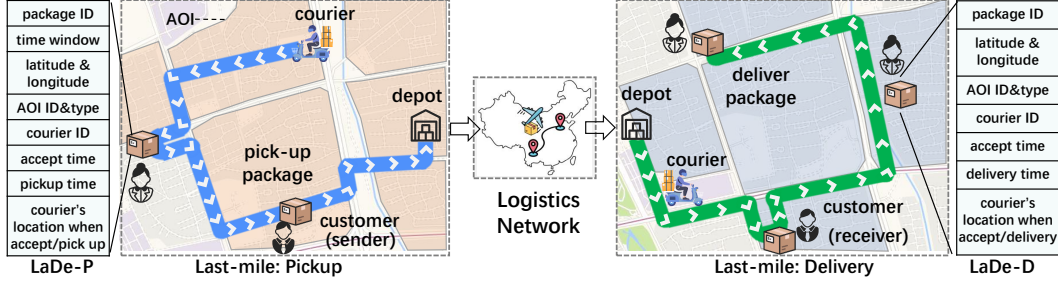


Figure 1: Overview of LaDe from last-mile delivery (better viewed in color), which includes two sub-datasets: LaDe-P from package pick-up process (i.e., couriers pick up packages from sender customers and return the depot) and LaDe-D from delivery process (i.e., couriers deliver packages from the depot to receiver customers).

Recent endeavors [10, 11, 12] focus on leveraging machine/deep learning techniques for problems in last-mile delivery research. A critical prerequisite for those researches is the availability of high-quality, large-scale datasets. Since such datasets have the potential to significantly accelerate advancements in specific fields, such as ImageNet [16] for computer vision and GLUE [17] for natural language processing. Nonetheless, in the domain of last-mile background research, a multitude of algorithms have been devised, but there is still an absence of a widely recognized, publicly accessible dataset. Consequently, research in this field has become concentrated within a limited number of industrial research laboratories, thereby restricting transparency and hindering research progress. Moreover, the lack of public datasets also poses a hurdle for industry practitioners to develop advanced algorithms for last-mile delivery.

To meet the rising calling for a public dataset, we propose LaDe, the first comprehensive Last-mile Delivery dataset collected by Cainiao. It contains both package pick-up and delivery data as depicted in Figure 1. LaDe has several merits: (1) *Large-scale*, covering 10,677k packages of 21k couriers across 6 months. To the best of our knowledge, this is the largest publicly available dataset. (2) *Comprehensive*, providing detailed information on package, location, task-event, and courier. (3) *Diverse*, collecting data from both pick-up and delivery processes across various cities. By virtue of these advantages, LaDe can be employed to evaluate a wide spectrum of last-mile-related tasks. In this paper, we investigate its properties by three tasks, including route prediction [13, 14, 15], estimated time of arrival prediction [10, 11, 12], and spatio-temporal graph forecasting [18, 19, 20]. Beyond these tasks, it is easy to integrate some of the aforementioned features to support additional tasks. We believe that such a large-scale dataset like LaDe is a critical resource for developing advanced algorithms under the context of last-mile delivery, as well as for providing critical training and benchmarking data for learning-based algorithms. Overall, we identify three key contributions of this work:

- **A New Dataset.** We collect, process, and release LaDe. The dataset boasts large-scale, comprehensive, and diverse characteristics. To the best of our knowledge, it is the first exhaustive, industry-scale last-mile delivery dataset. The dataset is publicly accessible at <https://huggingface.co/datasets/Cainiao-AI/LaDe>.
- **Comprehensive Data Analysis.** Extensive data analysis is conducted to depict and highlight the properties of the dataset. Based on the analysis, we introduce potential tasks supported by LaDe, from logistics operation management to spatio-temporal data mining, and beyond.
- **Benchmark on Real-World Tasks.** We benchmark this dataset by performing three representative tasks, including service route prediction, estimated time of arrival prediction, and spatio-temporal graph forecasting. The source codes for these tasks are provided to promote research in this field.

The remainder of this paper is structured as follows. Section 2 discusses related work, and Section 3 introduces the details of the dataset, including the methodology used to construct the dataset, and the statistics and properties of the dataset. In Section 4, we benchmark the dataset on three tasks and discuss the potential use of the data in related research fields.

2 Related Work

Dataset Perspective. To the best of our knowledge, there is no publicly available last-mile dataset containing both package pick-up and delivery data. The most relative effort comes from Amazon [21] (named AmazonData in this paper). It is a courier-operated sequence dataset proposed for a last-mile routing research challenge hosted by Amazon. Specifically, this dataset contains 9,184 historical routes performed by Amazon couriers in 2018 in five metropolitan areas in the United States. Despite the contribution of AmazonData to the research field, it still has three limitations: 1) Without pick-up data, it only contains data generated in the package delivery process; 2) Small scale, in terms of spatio-temporal range and the number of trajectories; 3) Lack of courier-related and task-event-related information, which prevents it from benefiting a wider group of researchers with different interests. In light of the above issues, we introduce an industry-scale, comprehensive dataset (i.e., LaDe) for researchers to develop and evaluate new ideas on real-world instances in last-mile delivery. The scale of LaDe is 5 times of AmazonData in terms of package number and 50 times in terms of trajectory number. We provide a detailed comparison of AmazonData and LaDe in Table 1.

Table 1: Comparison between LaDe and the related dataset.

Dataset	Time span	#Trajectories	#Couriers	#Packages	Delivery Data	Pick-up Data	Courier Info	Task-event Info
AmazonData	4 months	9k	-	2,182k	✓	×	×	×
LaDe	6 months	619k	21k	10,677k	✓	✓	✓	✓

Application Perspective. Overall, last-mile logistics is an emerging interdisciplinary research area connecting transportation and AI technology, in which deep learning methods have long been the most popular model [5]. Broadly speaking, there are four branches in this field: 1) Emerging trends and technologies, which focus on technological solutions and innovations in last-mile logistics, such as courier’s route and arrival time prediction [15, 12], self-service technologies [22], drone-assisted delivery [23]. 2) Last-mile-related data mining [24, 25], which aims to excavate the underlying patterns of knowledge from data generated by real-world operations for better logistics management. 3) Operational optimization, which focuses on optimizing last-mile operations and making better operational decisions, such as vehicle routing problem [7, 26], delivery scheduling [27], and facility location selection [28, 29]. 4) Supply chain structures, which focused on designing structures for last mile logistics, such as the network design [30]. We refer readers to the paper [5] for a more detailed, systematic classification of last-mile-related research. The proposed LaDe contains instances based on real operational data that researchers can use to advance the state-of-the-art in their fields and to expand its applications to industry settings.

3 Proposed Dataset: LaDe

In this section, we formally introduce the LaDe Dataset. First, we describe the data collection process, followed by a detailed discussion of LaDe’s data fields and dataset statistics. Finally, we conduct a comprehensive analysis to highlight its unique properties. The dataset can be freely downloaded at <https://huggingface.co/datasets/Cainiao-AI/LaDe> and noncommercially used with a custom license CC BY-NC 4.0².

3.1 Data Collection

This dataset is collected by Cainiao Network³, one of China’s largest logistics platforms, which handles a tremendous volume of packages each day. A typical process for shipping a package involves the following steps: 1) The customer (sender) places a package pick-up order through the online platform. 2) The platform dispatches the order to an appropriate courier. 3) The courier picks up the package within the specified time window and returns to the depot (this constitutes the package

²<https://creativecommons.org/licenses/by-nc/4.0/>

³<https://global.cainiao.com/>

pick-up process). 4) The package departs from the depot and traverses the logistics network until it reaches the target depot. 5) At the target depot, the delivery courier retrieves the package and delivers it to the recipient customer (known as the package delivery process). Among these steps, step 3 and 5 are referred to as the last-mile delivery, where couriers pick up/deliver packages from/to customers. Note that there is a notable difference between the pick-up and delivery scenarios. In the package delivery process, packages assigned to a particular courier are determined prior to the courier’s departure from the depot. Conversely, in the pick-up process, packages assigned to a courier are not settled at the beginning. Rather, they are revealed over time, as customers can request pick-ups at any time. The dynamic nature of package pick-up presents substantial challenges in the research field. To advocate more efforts for the challenge and make the data more diverse, LaDe contains two sub-datasets in both pick-up and delivery scenarios, named LaDe-P and LaDe-D, respectively.

Specifically, we collect millions of package pick-up/delivery data generated in 6 months from different cities in China. To increase the diversity, we carefully selected 5 cities - Shanghai, Hangzhou, Chongqing, Jilin, and Yantai - which possess distinct characteristics such as populations, more details can be found in Table 11 of Appendix A.2. A city contains different regions, with each region composed of several AOIs (Area of Interest) for logistics management. And a courier is responsible for picking up / delivering packages in several assigned AOIs. We give a simple illustration of the region-level and AOI-level segmentation of a city in Figure 2. To collect the data for each city, we first randomly select 30 regions in the city. Subsequently, we randomly sample couriers in each region and pick out all the selected couriers’ picked-up/delivery packages during the 6 months. To safeguard the privacy of both customers and couriers, we applied perturbations to the latitude and longitude points collected in the data. The accuracy of the latitude and longitude is limited to 10 meters. The data must not be assumed to indicate any of Cainiao’s business interests.

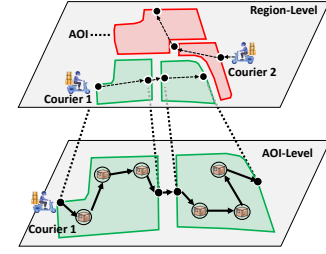


Figure 2: Region-level and AOI-level data.

3.2 Dataset Details & Statistics

In this subsection, we present the dataset details and its basic statistics. The detailed data field description of LaDe-P and LaDe-D can be found in Table 7 and Table 8 in Appendix A.1.

To facilitate the utilization and analysis of the dataset, we transform and arrange each sub-dataset into tabular data presented in CSV format. Each record in this format contains relevant information pertaining to a picked-up or delivered package, primarily addressing the “who, where, when” aspects. Specifically, the record specifies which courier picked up or delivered the package, the location of the package, and the corresponding time. The recorded information can be broadly categorized into four types: 1) package information, which records the package ID and time windows requirements (if applicable); 2) stop information, recording the package’s location information such as coordinates, AOI ID, and AOI type; 3) courier information, recording the courier’s ID, and each courier is equipped with a personal digital assistant (PDA), which will consistently report the status of a courier (e.g., GPS) to the platform; 4) task-event information, recording the features of package accept, pick-up or delivery event, including when the event happens and the courier’s location.

Overall, the package and task-event information can be recorded once the courier accepts the order, or finishes the order. Information about the stop comes from the geo-decoding system used in Cainiao, which can parse the input location address into its corresponding coordinates with a given accuracy. Table 2 shows the statistics of the LaDe-P. Due to the page limitation, please refer to Table 13 in Appendix A.2 for the statistics of the LaDe-D. Moreover, to intuitively illustrate the spatio-temporal characteristics of the dataset, we draw the spatial and temporal distribution of one city (Shanghai) in Figure 3 for one sub-dataset LaDe-P. From the Figure, we have the following observations. **Obs1:** Figure 3(a) shows that couriers’ work time starts from 8:00 and ends at 19:00. The volume of package pick-up has a peak at 9:00 am and 5:00 pm, respectively. **Obs2:** Figure 3(b) and Figure 3(c) shows the spatial distribution of packages, where the distance between consecutive packages in a courier’s route

Table 2: Statistics of LaDe-P. AvgETA stands for the average arrival time per package. AvgPackage means the average package number of a courier per day. The unit of AvgETA is minute.

City	Time span	Spatial span	#Trajectories	#Couriers	#Packages	#GPS points	AvgETA	AvgPackage
Shanghai	6 months	20km×20km	96k	4,502	1,450k	1,785k	151	15.0
Hangzhou	6 months	20km×20km	119k	5,347	2,130k	2,427k	146	17.8
Chongqing	6 months	20km×20km	83k	2,982	1,172k	1,475k	140	14.0
Yantai	6 months	20km×20km	71k	2,593	1,146k	1,641k	137	16.0
Jilin	6 months	20km×20km	18k	665	261k	399k	123	13.8

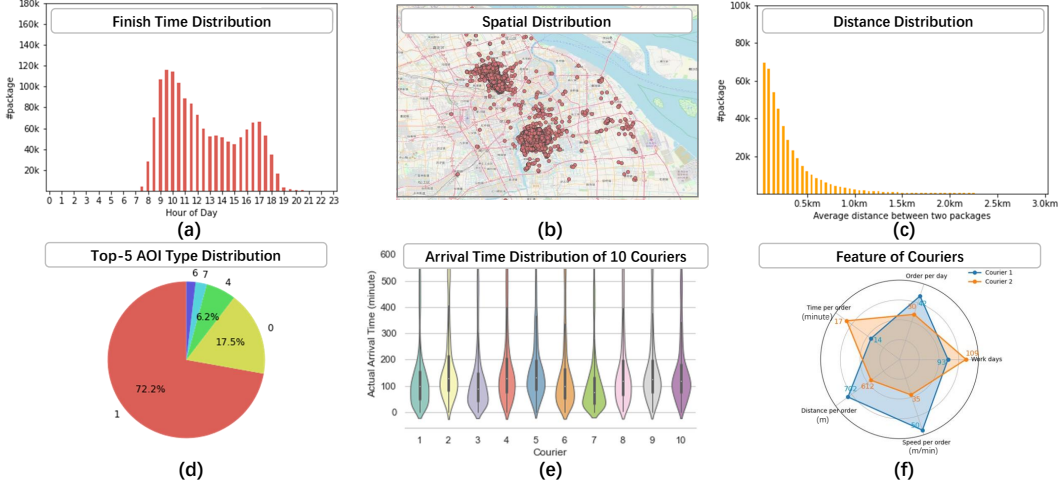


Figure 3: Spatial and temporal distribution of data in Shanghai of LaDe-P.

is usually within 1km. **Obs3:** Figure 3(d) shows the distribution of the top 5 AOI types in the data, illustrating that over 70% packages come from type 1. **Obs4:** Figure 3(e) shows the actual arrival time of 10 randomly selected couriers, from which we observed differences in the work efficiency of different couriers. It also shows that a majority of packages are picked up within 3 hours. **Obs5:** Figure 3(f) depicts the profile of two couriers in the dataset, where different characteristics such as work days, and average orders per day are observed.

3.3 Dataset Properties & Challenges

In this subsection, we present our primary data analysis to highlight its properties and the challenges they entail.

Large scale. LaDe contains in total 10,667k packages and 619k trajectories that consist of 16,755k GPS pings generated by 21k couriers, covering 5 cities over a total span of 6 months. The maximal package number of a courier one trip in the pick-up scenario and delivery scenario reaches 95 and 121, respectively. *Such large scale brings a significant challenge to algorithms in last-mile delivery.* To the best of our knowledge, this is the largest clean delivery dataset available to the research community, in terms of spatio-temporal coverage, the total number of packages, and the number of couriers’ trajectories.

Comprehensivity. LaDe aims to offer a wealth of information pertaining to last-mile delivery, encompassing various types of data such as detailed package information, task-event logs, courier trajectory details, and contextual features. The objective is to facilitate a broader range of research endeavors. *How to effectively leverage these comprehensive features to improve existing or inspire new tasks remains an open problem for researchers from different communities.*

Diversity. We increase the data’s diversity from two perspectives: (1) scenario diversity – we introduce scenario diversity by collecting two sub-datasets representing both pick-up and delivery

scenarios; (2) city diversity – we collect data from different cities to increase the diversity of the dataset. The cities in the dataset have different characteristics, leading to various spatio-temporal patterns in the dataset, where we give an illustration in Figure 4. For more information about the selected cities, please refer to Table 11 in Appendix A.1. *Such diversity brings the challenge of designing advanced models that can generalize well under cities with different characteristics.*

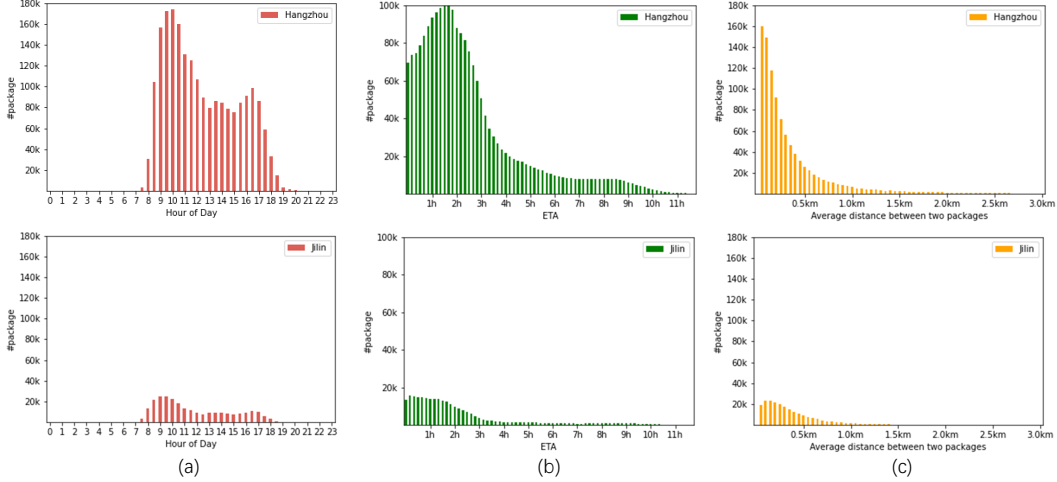


Figure 4: Diversity of cities. We select two cities, Hangzhou and Jilin, as an example to reveal their different spatio-temporal distributions. (a) The time distribution of packages in a day; (b) The ETA distribution of packages; (c) The distribution of the average distance between two consecutive packages in a courier’s route. A significant difference is observed in the above illustration.

Dynamism (only for LaDe-P). Compared to LaDe-D, the tasks of a courier in LaDe-P are not settled at the beginning of the day. Rather, they are revealed along with the pick-up process as customers can place an order at any time. *Such dynamism in courier tasks poses significant technical challenges in various research areas*, with one notable example being dynamic route optimization [31, 8].

Equipped with the above unique properties, LaDe offers the most extensive compilation of data for various research purposes background by last-mile delivery. It encompasses a variety of information across multiple domains, such as package details, event-based information, and courier information. Our aspiration is to make this abundant resource accessible to a broad spectrum of researchers, enabling them to undertake diverse and innovative studies.

4 Applications

To prove LaDe’s ability to support multiple tasks, we benchmark the dataset in three learning-based tasks, including route prediction, estimated time of arrival prediction, and spatio-temporal graph forecasting. Those tasks all come from the real-world application and we illustrate them in Figure 5. The code of relevant baselines in each task is released at <https://huggingface.co/datasets/Cainiao-AI/LaDe>. Note that the dataset can support far more than the three tasks, which we envision more possible applications from different research fields at the end of the section.

4.1 Route Prediction

A crucial task in last-mile delivery services (such as logistics and food delivery) is service route prediction [12, 15], which aims to estimate the future service route of a worker given his unfinished tasks at the request time.

Problem Definition. Formally, at a certain time t , a worker (i.e., courier) w can have n unfinished tasks, denoted by $\mathbf{X}_t^w = \{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\}$, where \mathbf{x}_i corresponds to the feature vector of a task i . Given a worker w ’s unfinished tasks at time t and route constraints \mathcal{C} (such as pick-up then delivery constraints), route prediction aims to learn a mapping function $\mathcal{F}_{\mathcal{C}}$ to predict the worker’s future ser-

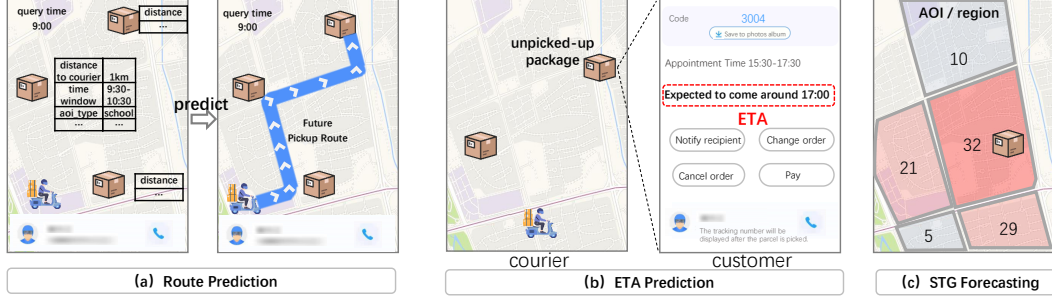


Figure 5: Illustration of three real-world applications. (a): Route prediction predicts the future pick-up route of a courier. (b): ETA prediction estimates the courier’s arrival time for picking up or delivering packages. (c): STG forecasting predicts the future package number in given regions/AOIs.

vice route $\hat{\pi}$ which can satisfy the given route constraints \mathcal{C} , formulated as: $\mathcal{F}_{\mathcal{C}}(\mathbf{X}_t^w) = [\pi_1, \pi_2 \cdots \pi_n]$, where π_i means that the i -th node in the route is task π_i . And $\pi_i \in \{1, \cdots n\}$ and $\pi_i \neq \pi_j$ if $i \neq j$.

Dataset. We choose LaDe-P as the dataset to conduct the experiment. The training, validation, and test set is split chronologically using a ratio of 6:2:2. Due to the space limit, we select three out of the five cities for conducting experiments, including Shanghai, Chongqing, and Yantai.

Baselines & Hyperparameters. We run six baselines on LaDe. 1) Basic methods: TimeGreedy [13] and DistanceGreedy [13]. 2) Machine learning method: Osquire [13]. 3) Deep learning models: DeepRoute [14], FDNET [12], and Graph2Route [15]. Hyperparameters search is performed on the validation set by evaluating hidden size in $\{16, 32, 64, 128\}$. We set the learning rate to 0.0001 and batch size to 64 for all deep-learning models. More details about the baselines and metrics can be found in Appendix B.1.

Results. Following [15], we adopt $\text{HR}@k$, KRC, LMD, and ED to evaluate model performance. Higher KRC, $\text{HR}@k$, and lower LSD and ED mean better performance. The number of packages in each sample is in $(0, 25]$. Table 3 shows the results of different methods on LaDe. It can be observed that basic models perform poorly since they can only make use of distance or time information. Deep models generally achieve better performance than shallow models, because of their ability to model abundant spatial and temporal features. This further proves the importance of the comprehensive information provided by LaDe for building more powerful models. Among deep models, Graph2Route performs the best due to its ability to model the underlying graph correlation of different packages.

Table 3: Experiment Results of Route Prediction.

Method	Chongqing				Shanghai				Yantai			
	HR@3	KRC	LSD	ED	HR@3	KRC	LSD	ED	HR@3	KRC	LSD	ED
Time-Greedy	63.86 \pm 0.00	44.16 \pm 0.00	3.91 \pm 0.00	1.74 \pm 0.00	59.81 \pm 0.00	39.93 \pm 0.00	5.20 \pm 0.00	2.24 \pm 0.00	61.23 \pm 0.00	39.64 \pm 0.00	4.62 \pm 0.00	1.85 \pm 0.00
Distance-Greedy	62.99 \pm 0.00	41.48 \pm 0.00	4.22 \pm 0.00	1.60 \pm 0.00	61.07 \pm 0.00	42.84 \pm 0.00	5.35 \pm 0.00	1.94 \pm 0.00	62.34 \pm 0.00	40.82 \pm 0.00	4.49 \pm 0.00	1.64 \pm 0.00
Or-Tools	64.19 \pm 0.00	43.09 \pm 0.00	3.67 \pm 0.00	1.55 \pm 0.00	62.50 \pm 0.00	44.81 \pm 0.00	4.69 \pm 0.00	1.88 \pm 0.00	63.27 \pm 0.00	42.31 \pm 0.00	3.94 \pm 0.00	1.59 \pm 0.00
LightGBM	71.55 \pm 0.00	54.53 \pm 0.00	2.63 \pm 0.00	1.54 \pm 0.00	70.63 \pm 0.00	54.48 \pm 0.00	3.27 \pm 0.00	1.92 \pm 0.00	70.41 \pm 0.00	52.90 \pm 0.00	2.87 \pm 0.00	1.59 \pm 0.00
FDNET	69.98 \pm 0.32	52.07 \pm 0.38	3.36 \pm 0.04	1.51 \pm 0.01	69.05 \pm 1.23	52.72 \pm 1.72	4.08 \pm 0.25	1.86 \pm 0.03	69.08 \pm 0.61	50.62 \pm 1.20	3.60 \pm 0.15	1.57 \pm 0.02
DeepRoute	72.09 \pm 0.39	55.72 \pm 0.40	2.66 \pm 0.06	1.51 \pm 0.01	71.66 \pm 0.10	56.20 \pm 0.23	3.26 \pm 0.07	1.86 \pm 0.01	71.44 \pm 0.28	54.74 \pm 0.49	2.80 \pm 0.02	1.53 \pm 0.02
CPRoute	72.55 \pm 0.23	55.76 \pm 0.32	2.70 \pm 0.01	1.49 \pm 0.02	71.73 \pm 0.08	56.17 \pm 0.04	3.39 \pm 0.02	1.84 \pm 0.00	71.76 \pm 0.04	54.84 \pm 0.03	2.99 \pm 0.01	1.53 \pm 0.00
Graph2Route	72.31 \pm 0.20	56.08 \pm 0.14	2.53 \pm 0.01	1.50 \pm 0.01	71.69 \pm 0.10	56.53 \pm 0.10	3.12 \pm 0.01	1.86 \pm 0.00	71.52 \pm 0.14	55.02 \pm 0.10	2.71 \pm 0.01	1.54 \pm 0.00
M2G4RTP	72.44 \pm 0.11	56.15 \pm 0.04	2.55 \pm 0.03	1.50 \pm 0.00	71.73 \pm 0.06	56.34 \pm 0.08	3.16 \pm 0.02	1.86 \pm 0.01	71.73 \pm 0.01	55.02 \pm 0.17	2.78 \pm 0.00	1.53 \pm 0.01
DRL4Route	73.12 \pm 0.06	57.23 \pm 0.12	2.43 \pm 0.01	1.48 \pm 0.01	72.18 \pm 0.15	57.20 \pm 0.18	3.06 \pm 0.02	1.84 \pm 0.01	72.07 \pm 0.06	55.94 \pm 0.10	2.62 \pm 0.00	1.51 \pm 0.00

4.2 Estimated Time of Arrival Prediction

Estimated Time of Arrival (ETA) prediction aims to forecast when the task is going to be finished, e.g., the delivery time of a package. It is one of the most important tasks in many delivery platforms since it directly influences customers’ experience [10].

Problem Definition. Given an ETA query of worker w at time t , i.e., $q = \{t, \mathbf{X}_t^w\}$, where $\mathbf{X}_t^w = \{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\}$ is the courier’s unfinished packages, ETA prediction aims to build a model \mathcal{F} that

can map the input query to the arrival time (i.e., pick-up/delivery time) \mathbf{Y} for the unfinished package set: $\mathcal{F}(q) \mapsto \mathbf{Y} = \{y_1, \dots, y_n\}$, where $y_i = t_i^{\text{actual}} - t$ and t_i^{actual} is the actual arrival time of task i .

Dataset. LaDe-D is utilized for this experiment (note that LaDe-P can also be used for this task). We split the data into training, validation, and test sets chronologically in a ratio of 6:2:2.

Baselines & Hyperparameters. Five baselines are evaluated for the task, including a simple speed-based method SPEED, machine learning methods LightGBM [32] and KNN [33], and deep models Multi-Layer Perceptron (MLP) and FDNET [12]. We also perform hyperparameters search on the validation set by hidden size in $\{16, 32, 64, 128\}$ for all deep models. The learning rate and batch size are set to 0.00005 and 32 for all models. See more details in Appendix B.2.

Results. MAE, RMSE, and ACC@20(%) are used to evaluate the performance of time prediction models. Higher ACC@20 and lower MAE and RMSE indicate better performance. From the results shown in Table 4, we can see that learning-based models outperform SPEED by a large margin because of their ability to model multiple spatio-temporal factors. We also observe a huge performance gap of the same method in different cities. For example, the best model, RANKETPA, achieves 73.67% in terms of ACC@20 in Shanghai, while it gets a much lower accuracy of 57.83% and 54.45% in the other two datasets. It deserves further study to build a more powerful model that can generalize well in cities with different properties.

Table 4: Experiment results of ETA prediction.

Method	Shanghai			Yantai			Chongqing		
	MAE ↓	RMSE ↓	ACC@20 ↑	MAE ↓	RMSE ↓	ACC@20 ↑	MAE ↓	RMSE ↓	ACC@20 ↑
SPEED	26.68 ±0.00	31.31 ±0.00	52.57 ±0.00	33.97 ±0.00	40.27 ±0.00	42.03 ±0.00	35.55 ±0.00	42.06 ±0.00	41.10 ±0.00
KNN	25.22 ±0.00	29.57 ±0.00	65.71 ±0.00	28.10 ±0.00	33.80 ±0.00	45.33 ±0.00	29.45 ±0.00	35.19 ±0.00	43.68 ±0.00
LightGBM	17.24 ±0.00	20.40 ±0.00	67.44 ±0.00	23.32 ±0.00	27.82 ±0.00	51.22 ±0.00	24.22 ±0.00	27.99 ±0.00	48.80 ±0.00
MLP	16.16 ±0.02	19.31 ±0.01	72.17 ±0.10	22.18 ±0.06	26.38 ±0.06	54.98 ±0.17	23.82 ±0.02	28.24 ±0.02	52.74 ±0.16
FDNET	18.81 ±1.23	21.15 ±2.47	64.30 ±1.43	22.41 ±0.50	26.00 ±0.63	54.67 ±1.55	22.54 ±0.91	24.53 ±0.92	46.65 ±4.82
RankETPA	15.76 ±0.05	19.13 ±0.08	73.67 ±0.15	21.36 ±0.07	25.52 ±0.08	57.83 ±0.07	23.37 ±0.01	27.93 ±0.04	54.45 ±0.10
M2G4RTP	8.23 ±0.02	9.59 ±0.03	91.01 ±0.51	17.21 ±1.57	19.71 ±1.88	69.20 ±0.39	17.96 ±0.25	19.74 ±0.31	65.97 ±0.32

4.3 Spatio-Temporal Graph (STG) Forecasting

LaDe contains the package data with information that records when and where the package order is placed. Based on this, the package number of a region within a certain period can be calculated. In this way, LaDe also contributes as a new dataset to another well-known task – *spatio-temporal graph forecasting* [18, 19, 34], which aims to predict future graph signals given its historical observations.

Problem Definition. Let $\mathcal{G} = \{\mathcal{V}, \mathcal{E}, \mathbf{A}\}$ represent a graph with V nodes, where \mathcal{V}, \mathcal{E} are the node set and edge set, respectively. $\mathbf{A} \in \mathbb{R}^{V \times V}$ is a weighted adjacency matrix to describe the graph topology. For $\mathcal{V} = \{v_1, \dots, v_V\}$, let $\mathbf{x}_t \in \mathbb{R}^{F \times V}$ denote F -dimensional signals generated by the V nodes at time t . Given historical graph signals $\mathbf{x}^h = [\mathbf{x}_1, \dots, \mathbf{x}_{T_h}]$ of T_h time steps and the graph \mathcal{G} as inputs, STG forecasting aims at learning a function \mathcal{F} to predict future graph signals \mathbf{x}^p , formulated as: $\mathcal{F} : (\mathbf{x}^h; \mathcal{G}) \rightarrow [\mathbf{x}_{T_h+1}, \dots, \mathbf{x}_{T_h+T_p}] := \mathbf{x}^p$, where T_p is the forecasting horizon.

Dataset. LaDe-P is used to conduct this experiment. More experiment details can be found in Appendix B.3. Each node corresponds to a region within the city. The signal of each node represents the number of packages picked up during a particular time stamp. We set the time interval to be 1 hour. Our objective is to leverage the data from the previous 24 hours to predict the package volume for the subsequent 24 hours. We use the ratio of 6:2:2 for training, evaluation, and testing sets based on the chronological order of the timestamps.

Baselines & Hyperparameters. We evaluate eight baselines, including a traditional method (i.e., HA [35]), and recent deep learning models, including DCRNN [18], STGCN [36], GWNET [37], ASTGCN [38], MTGNN [39], AGCRN [20] and STGNCDE [40]. We set the hidden size, learning rate, and batch size to 32, 0.001, and 32 for all models.

Results. MAE and RMSE are used as the metrics, and results are shown in Table 5. Comparing the methods, we can observe that the baseline method, HA (Historical Average), achieves relatively higher MAE and RMSE values across all three cities. This indicates that simply using historical averages to predict future spatio-temporal graph data is not as effective as the other methods. The results of the different methods may vary slightly depending on the city. For instance, in Shanghai, GWNET, ASTGCN, and MTGNN exhibit similar performance, while in Hangzhou and Chongqing, MTGNN and ASTGCN achieve the lowest errors, respectively.

Table 5: Experimental results of spatio-temporal graph prediction.

Method	Shanghai		Hangzhou		Chongqing	
	MAE ↓	RMSE ↓	MAE ↓	RMSE ↓	MAE ↓	RMSE ↓
HA [35]	4.63	9.91	4.78	10.53	2.44	5.30
DCRNN [18]	3.69 ± 0.09	7.08 ± 0.12	4.14 ± 0.02	7.35 ± 0.07	2.75 ± 0.07	5.11 ± 0.12
STGCN [36]	3.04 ± 0.02	6.42 ± 0.05	3.01 ± 0.04	5.98 ± 0.10	2.16 ± 0.01	4.38 ± 0.03
GWNET [37]	3.16 ± 0.06	6.56 ± 0.11	3.22 ± 0.03	6.32 ± 0.04	2.22 ± 0.03	4.45 ± 0.05
ASTGCN [38]	3.12 ± 0.06	6.48 ± 0.14	3.09 ± 0.04	6.06 ± 0.10	2.11 ± 0.02	4.24 ± 0.03
MTGNN [39]	3.13 ± 0.04	6.51 ± 0.13	3.01 ± 0.01	5.83 ± 0.03	2.15 ± 0.01	4.28 ± 0.05
AGCRN [20]	3.93 ± 0.03	7.99 ± 0.08	4.00 ± 0.03	7.88 ± 0.06	2.46 ± 0.00	4.87 ± 0.01
STGCNDE [40]	3.74 ± 0.15	7.27 ± 0.16	3.55 ± 0.04	6.88 ± 0.10	2.32 ± 0.07	4.52 ± 0.07

4.4 Discussion of Other Potential Tasks

In addition to primary tasks, the dataset can provide substantial support for a wide range of other tasks within the context of last-mile delivery. In the future, we plan to explore a wider range of applications on LaDe. Here we present a list of tasks supported by LaDe in Table 6, highlighting the minimal required information necessary for performing each task using LaDe. This effectively showcases LaDe’s remarkable multi-task support capability.

Table 6: Supported tasks with the minimal required information.

Task	Package Info	Stop Info	Courier Info	Task-event Info	Context
Vehicle Routing [7]	✓	✓		✓	
Delivery Scheduling [27]	✓	✓		✓	
Last-Mile Data Mining [41, 24]	✓	✓	✓	✓	✓
Spatial Crowdsourcing [42, 27, 43]	✓	✓	✓	✓	
Time Prediction [44, 45]	✓	✓	✓	✓	
Route Prediction [12, 15]	✓	✓	✓	✓	
STG Forecasting [19, 34]	✓	✓			✓

4.5 Data Limitations

In this subsection, we introduce two potential limitations associated with the utilization of LaDe. The first one is the limited country coverage. LaDe is collected from the last-mile delivery data in the Cainiao logistic platform, which majorly targets the cities in China. The second limitation arises from the absence of parts of the courier’s trajectory point. In the actual operation process, the platform cannot locate the location of couriers due to the problems of PDA (personal digital device) or GPS locating problems. As a result, there are some missing values in the courier’s location at the accept time and pick-up/delivery time. The missing location rate when accepting orders is about 40%, and the missing rate of GPS when picking up is 29% in LaDe-P.

5 Conclusion

In this paper, we introduced LaDe, the first comprehensive industry-scale last-mile delivery dataset, addressing the lack of a widely accepted, publicly available dataset for last-mile delivery research. LaDe provides a critical resource for researchers and practitioners to develop advanced algorithms in the context of last-mile delivery, with its large-scale, comprehensive, diverse, and dynamic characteristics enabling it to serve as a new and challenging benchmark dataset. We have also

demonstrated the versatility of LaDe by benchmarking it on three real-world tasks, showcasing its potential applications in various research fields. The source code is released along with the dataset to drive the development of this area. By releasing LaDe, we aim to promote further research and collaboration among researchers from different fields, encouraging them to utilize it for developing novel algorithms and models, as well as comparing and validating their methods against state-of-the-art approaches. We believe that LaDe will significantly contribute to ongoing efforts to improve efficiency, cost-effectiveness, and customer satisfaction in last-mile delivery, ultimately benefiting the research community and logistics industry.

References

- [1] E. Macioszek, “First and last mile delivery—problems and issues,” in *Advanced Solutions of Transport Systems for Growing Mobility: 14th Scientific and Technical Conference "Transport Systems. Theory & Practice 2017" Selected Papers*. Springer, 2018, pp. 147–154.
- [2] M. Ranathunga, A. Wijayanayake, and D. Niwunhella, “Solution approaches for combining first-mile pickup and last-mile delivery in an e-commerce logistic network: A systematic literature review,” in *2021 International Research Conference on Smart Computing and Systems Engineering (SCSE)*, vol. 4. IEEE, 2021, pp. 267–275.
- [3] N. Boysen, S. Fedtke, and S. Schwerdfeger, “Last-mile delivery concepts: a survey from an operational research perspective,” *Or Spectrum*, vol. 43, pp. 1–58, 2021.
- [4] M. Ratnagiri, C. O’Dwyer, L. E. Beaver, H. Bang, B. Chalaki, and A. A. Malikopoulos, “A scalable last-mile delivery service: From simulation to scaled experiment,” in *2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC)*. IEEE, 2022, pp. 4163–4168.
- [5] J. Olsson, D. Hellström, and H. Pålsson, “Framework of last mile logistics research: A systematic review of the literature,” *Sustainability*, vol. 11, no. 24, p. 7131, 2019.
- [6] R. Mangiaracina, A. Perego, A. Seghezzi, and A. Tumino, “Innovative solutions to increase last-mile delivery efficiency in b2c e-commerce: a literature review,” *International Journal of Physical Distribution & Logistics Management*, 2019.
- [7] Y. Zeng, Y. Tong, and L. Chen, “Last-mile delivery made practical: An efficient route planning framework with theoretical guarantees,” *Proceedings of the VLDB Endowment*, vol. 13, no. 3, pp. 320–333, 2019.
- [8] X. Li, W. Luo, M. Yuan, J. Wang, J. Lu, J. Wang, J. Lü, and J. Zeng, “Learning to optimize industry-scale dynamic pickup and delivery problems,” in *2021 IEEE 37th International Conference on Data Engineering (ICDE)*. IEEE, 2021, pp. 2511–2522.
- [9] P. Almasan, J. Suárez-Varela, K. Rusek, P. Barlet-Ros, and A. Cabellos-Aparicio, “Deep reinforcement learning meets graph neural networks: exploring a routing optimization use case,” *Computer Communications*, vol. 196, pp. 184–194, 2022.
- [10] F. Wu and L. Wu, “DeepETA: A spatial-temporal sequential neural network model for estimating time of arrival in package delivery system,” in *Proceedings of the AAAI Conference on Artificial Intelligence*, 2019, pp. 774–781.
- [11] A. C. de Araujo and A. Etemad, “End-to-end prediction of parcel delivery time with deep learning for smart-city applications,” *IEEE Internet of Things Journal*, 2021.
- [12] C. Gao, F. Zhang, G. Wu, Q. Hu, Q. Ru, J. Hao, R. He, and Z. Sun, “A deep learning method for route and time prediction in food delivery service,” in *KDD*, 2021, pp. 2879–2889.
- [13] Y. Zhang, Y. Liu, G. Li, Y. Ding, N. Chen, H. Zhang, T. He, and D. Zhang, “Route prediction for instant delivery,” *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, vol. 3, no. 3, p. Article 124, 2019.
- [14] H. Wen, Y. Lin, F. Wu, H. Wan, S. Guo, L. Wu, C. Song, and Y. Xu, “Package pick-up route prediction via modeling couriers’ spatial-temporal behaviors,” in *ICDE*. IEEE, 2021, pp. 2141–2146.

- [15] H. Wen, Y. Lin, X. Mao, F. Wu, Y. Zhao, H. Wang, J. Zheng, L. Wu, H. Hu, and H. Wan, "Graph2route: A dynamic spatial-temporal graph neural network for pick-up and delivery route prediction," in *Proceedings of the 28th ACM SIGKDD Conference on Knowledge Discovery and Data Mining*, 2022, pp. 4143–4152.
- [16] J. Deng, W. Dong, R. Socher, L.-J. Li, K. Li, and L. Fei-Fei, "Imagenet: A large-scale hierarchical image database," in *2009 IEEE conference on computer vision and pattern recognition*. Ieee, 2009, pp. 248–255.
- [17] A. Wang, A. Singh, J. Michael, F. Hill, O. Levy, and S. R. Bowman, "Glue: A multi-task benchmark and analysis platform for natural language understanding," *arXiv preprint arXiv:1804.07461*, 2018.
- [18] Y. Li, R. Yu, C. Shahabi, and Y. Liu, "Diffusion convolutional recurrent neural network: Data-driven traffic forecasting," in *International Conference on Learning Representations*, 2018.
- [19] H. Yao, F. Wu, J. Ke, X. Tang, Y. Jia, S. Lu, P. Gong, J. Ye, and Z. Li, "Deep multi-view spatial-temporal network for taxi demand prediction," in *Proceedings of the AAAI conference on artificial intelligence*, vol. 32, no. 1, 2018.
- [20] L. Bai, L. Yao, C. Li, X. Wang, and C. Wang, "Adaptive graph convolutional recurrent network for traffic forecasting," *Advances in neural information processing systems*, vol. 33, pp. 17 804–17 815, 2020.
- [21] D. Merchán, J. Arora, J. Pachon, K. Konduri, M. Winkenbach, S. Parks, and J. Nosal, "2021 amazon last mile routing research challenge: Data set," *Transportation Science*, 2022.
- [22] Y. Vakulenko, D. Hellström, and K. Hjort, "What's in the parcel locker? exploring customer value in e-commerce last mile delivery," *journal of Business Research*, vol. 88, pp. 421–427, 2018.
- [23] E. Taniguchi, R. G. Thompson, and A. G. Qureshi, "Modelling city logistics using recent innovative technologies," *Transportation Research Procedia*, vol. 46, pp. 3–12, 2020.
- [24] S. Ruan, C. Long, X. Yang, T. He, R. Li, J. Bao, Y. Chen, S. Wu, J. Cui, and Y. Zheng, "Discovering actual delivery locations from mis-annotated couriers' trajectories," in *2022 IEEE 38th International Conference on Data Engineering (ICDE)*. IEEE, 2022, pp. 3241–3253.
- [25] S. Ruan, C. Long, J. Bao, C. Li, Z. Yu, R. Li, Y. Liang, T. He, and Y. Zheng, "Learning to generate maps from trajectories," in *Proceedings of the AAAI conference on artificial intelligence*, vol. 34, no. 01, 2020, pp. 890–897.
- [26] U. Breunig, R. Baldacci, R. F. Hartl, and T. Vidal, "The electric two-echelon vehicle routing problem," *Computers & Operations Research*, vol. 103, pp. 198–210, 2019.
- [27] S. Han, L. Zhao, K. Chen, Z.-w. Luo, and D. Mishra, "Appointment scheduling and routing optimization of attended home delivery system with random customer behavior," *European Journal of Operational Research*, vol. 262, no. 3, pp. 966–980, 2017.
- [28] M. Jahangiriesmaili, S. Bahrani, and M. J. Roorda, "Solution of two-echelon facility location problems by approximation methods," *Transportation Research Record*, vol. 2610, no. 1, pp. 1–9, 2017.
- [29] A. Kedia, D. Kusumastuti, and A. Nicholson, "Locating collection and delivery points for goods' last-mile travel: A case study in new zealand," *Transportation Research Procedia*, vol. 46, pp. 85–92, 2020.
- [30] S. F. W. Lim and J. S. Srai, "Examining the anatomy of last-mile distribution in e-commerce omnichannel retailing: A supply network configuration approach," *International Journal of Operations & Production Management*, 2018.
- [31] B. Yao, C. McLean, and H. Yang, "Robust optimization of dynamic route planning in same-day delivery networks with one-time observation of new demand," *Networks*, vol. 73, no. 4, pp. 434–452, 2019.

- [32] G. Ke, Q. Meng, T. Finley, T. Wang, W. Chen, W. Ma, Q. Ye, and T.-Y. Liu, “Lightgbm: A highly efficient gradient boosting decision tree,” *Advances in neural information processing systems*, vol. 30, 2017.
- [33] J. Song, R. Wen, C. Xu, and J. W. E. Tay, “Service time prediction for last-yard delivery,” in *2019 IEEE International Conference on Big Data (Big Data)*. IEEE, 2019, pp. 3933–3938.
- [34] J. Simeunović, B. Schubnel, P.-J. Alet, and R. E. Carrillo, “Spatio-temporal graph neural networks for multi-site pv power forecasting,” *IEEE Transactions on Sustainable Energy*, vol. 13, no. 2, pp. 1210–1220, 2021.
- [35] J. Zhang, Y. Zheng, and D. Qi, “Deep spatio-temporal residual networks for citywide crowd flows prediction,” in *AAAI*, 2017, pp. 1655–1661.
- [36] B. Yu, H. Yin, and Z. Zhu, “Spatio-temporal graph convolutional networks: A deep learning framework for traffic forecasting,” in *IJCAI*, 2018.
- [37] Z. Wu, S. Pan, G. Long, J. Jiang, and C. Zhang, “Graph wavenet for deep spatial-temporal graph modeling,” in *IJCAI*, 7 2019, pp. 1907–1913.
- [38] S. Guo, Y. Lin, N. Feng, C. Song, and H. Wan, “Attention based spatial-temporal graph convolutional networks for traffic flow forecasting,” in *Proceedings of the AAAI conference on artificial intelligence*, vol. 33, no. 01, 2019, pp. 922–929.
- [39] Z. Wu, S. Pan, G. Long, J. Jiang, X. Chang, and C. Zhang, “Connecting the dots: Multivariate time series forecasting with graph neural networks,” in *Proceedings of the 26th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining*, 2020, pp. 753–763.
- [40] J. Choi, H. Choi, J. Hwang, and N. Park, “Graph neural controlled differential equations for traffic forecasting,” in *Proceedings of the AAAI Conference on Artificial Intelligence*, vol. 36, no. 6, 2022, pp. 6367–6374.
- [41] S. Ji, Y. Zheng, Z. Wang, and T. Li, “Alleviating users’ pain of waiting: Effective task grouping for online-to-offline food delivery services,” in *The World Wide Web Conference*, 2019, pp. 773–783.
- [42] C. Chen, D. Zhang, X. Ma, B. Guo, L. Wang, Y. Wang, and E. Sha, “Crowddeliver: Planning city-wide package delivery paths leveraging the crowd of taxis,” *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 6, pp. 1478–1496, 2016.
- [43] C. Chen, S. Yang, Y. Wang, B. Guo, and D. Zhang, “Crowdexpress: a probabilistic framework for on-time crowdsourced package deliveries,” *IEEE transactions on big data*, vol. 8, no. 3, pp. 827–842, 2020.
- [44] S. Ruan, Z. Xiong, C. Long, Y. Chen, J. Bao, T. He, R. Li, S. Wu, Z. Jiang, and Y. Zheng, “Doing in one go: delivery time inference based on couriers’ trajectories,” in *Proceedings of the 26th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining*, 2020, pp. 2813–2821.
- [45] S. Ruan, C. Long, Z. Ma, J. Bao, T. He, R. Li, Y. Chen, S. Wu, and Y. Zheng, “Service time prediction for delivery tasks via spatial meta-learning,” in *Proceedings of the 28th ACM SIGKDD Conference on Knowledge Discovery and Data Mining*, 2022, pp. 3829–3837.
- [46] M. G. Kendall, “A new measure of rank correlation,” *Biometrika*, vol. 30, no. 1/2, pp. 81–93, 1938.
- [47] J. Nerbonne, W. Heeringa, and P. Kleiweg, “Edit distance and dialect proximity,” *Time Warps, String Edits and Macromolecules: The theory and practice of sequence comparison*, vol. 15, 1999.
- [48] M.-C. Popescu, V. E. Balas, L. Perescu-Popescu, and N. Mastorakis, “Multilayer perceptron and neural networks,” *WSEAS Transactions on Circuits and Systems*, vol. 8, no. 7, pp. 579–588, 2009.

Checklist

The checklist follows the references. Please read the checklist guidelines carefully for information on how to answer these questions. For each question, change the default **[TODO]** to **[Yes]**, **[No]**, or **[N/A]**. You are strongly encouraged to include a **justification to your answer**, either by referencing the appropriate section of your paper or providing a brief inline description. For example:

- Did you include the license to the code and datasets? **[Yes]** See Section ??.
- Did you include the license to the code and datasets? **[No]** The code and the data are proprietary.
- Did you include the license to the code and datasets? **[N/A]**

Please do not modify the questions and only use the provided macros for your answers. Note that the Checklist section does not count towards the page limit. In your paper, please delete this instructions block and only keep the Checklist section heading above along with the questions/answers below.

1. For all authors...
 - (a) Do the main claims made in the abstract and introduction accurately reflect the paper’s contributions and scope? **[Yes]**
 - (b) Did you describe the limitations of your work? **[Yes]** See Section 4.5.
 - (c) Did you discuss any potential negative societal impacts of your work? **[Yes]** See Section 3.1
 - (d) Have you read the ethics review guidelines and ensured that your paper conforms to them? **[Yes]**
2. If you are including theoretical results...
 - (a) Did you state the full set of assumptions of all theoretical results? **[N/A]**
 - (b) Did you include complete proofs of all theoretical results? **[N/A]**
3. If you ran experiments (e.g. for benchmarks)...
 - (a) Did you include the code, data, and instructions needed to reproduce the main experimental results (either in the supplemental material or as a URL)? **[Yes]** See Introduction.
 - (b) Did you specify all the training details (e.g., data splits, hyperparameters, how they were chosen)? **[Yes]** See Section 4.
 - (c) Did you report error bars (e.g., with respect to the random seed after running experiments multiple times)? **[Yes]**
 - (d) Did you include the total amount of compute and the type of resources used (e.g., type of GPUs, internal cluster, or cloud provider)? **[N/A]**
4. If you are using existing assets (e.g., code, data, models) or curating/releasing new assets...
 - (a) If your work uses existing assets, did you cite the creators? **[Yes]**
 - (b) Did you mention the license of the assets? **[Yes]** See Section 1.
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 - (d) Did you discuss whether and how consent was obtained from people whose data you’re using/curating? **[Yes]** See Section 3.1.
 - (e) Did you discuss whether the data you are using/curating contains personally identifiable information or offensive content? **[Yes]** See Section 3.1.
5. If you used crowdsourcing or conducted research with human subjects...
 - (a) Did you include the full text of instructions given to participants and screenshots, if applicable? **[N/A]**
 - (b) Did you describe any potential participant risks, with links to Institutional Review Board (IRB) approvals, if applicable? **[N/A]**

- (c) Did you include the estimated hourly wage paid to participants and the total amount spent on participant compensation? [N/A]

Appendix

A Detailed Dataset Description

A.1 Data Field

Table 7: Description of data fields of LaDe-P.

Data field	Description	Unit/format
Package information		
package_id	Unique identifier of each package	Id
time_window_start	start of the required time window	Time
time_window_end	end of the required time window	Time
Stop information		
lng/lat	Coordinates of each stop	Float
city	City	String
region_id	Id of the Region	String
aoi_id	Id of the AOI (Area of Interest)	Id
aoi_type	Type of the AOI	Categorical
Courier Information		
courier_id	Id of the courier	Id
Task-event Information		
accept_time	The time when the courier accepts the task	Time
accept_gps_time	The time of the GPS point whose time is the closest to accept time	Time
accept_gps_lng/accept_gps_lat	Coordinates when the courier accept the task	Float
pickup_time	The time when the courier picks up the task	Time
pickup_gps_time	The time of the GPS point whose time is the closest to the pickup_time	Time
pickup_gps_lng/got_gps_lat	Coordinates when the courier picks up the task	Float
Context information		
ds	the date of the package pickup	Date

Table 8: Description of data fields of LaDe-D.

Data field	Description	Unit/format
Package information		
package_id	Unique identifier of each package	Id
Stop information		
lng/lat	Coordinates of each stop	Float
city	City	String
region_id	Id of the region	Id
aoi_id	Id of the AOI	Id
aoi_type	Type of the AOI	Categorical
Courier Information		
courier_id	Id of the courier	Id
Task-event Information		
accept_time	The time when the courier accept the task	Time
accept_gps_time	The time of the GPS point whose time is the closest to accept time	Time
accept_gps_lng/accept_gps_lat	Coordinates when the courier accept the task	Float
delivery_time	The time when courier finishes delivering the task	Time
delivery_gps_time	The time of the GPS point whose time is the closest to the got time	Time
delivery_gps_lng/delivery_gps_lat	Coordinates when the courier finish the task	Float
Context information		
ds	the date of the package delivery	Date

Table 9: Description of data fields of Detailed Trajectory.

Data field	Description	Unit/format
ds	The date of the trajectory	Date
courier_id	Id of the courier	Id
gps_time	The time when the trajectory point is recorded	Time
lng/lat	Coordinates of the courier	Float

Table 10: Description of data fields of Road Network.

Data field	Description	Unit/format
id	Unique identifier of the road	Id
road_id	Id of a street or place name	Id
code	4 digit code (between 1000 and 9999) defining the geographical features of a road	Id
fclass	Class name of the road	String
ref	Reference number of the road	String
oneway	Whether the road is a oneway road	String
maxspeed	Max allowed speed in km/h	Int
layer	Relative layering of roads	Int
bridge	Whether the road is on a bridge	String
tunnel	Whether the road is in a tunnel	String
city	City of the road	String
geometry	A geometry type composed of one or more line segments	String

A.2 Data Statistics

Table 13 shows the detailed statistics of LaDe-D.

B Experiments Details

B.1 Experiment Details of Route Prediction

Methods. We adopt the following methods for experiments:

- TimeGreedy [13]: A greedy algorithm, which ranks all the candidate tasks by sorting their remaining time.
- DistanceGreedy [13]: A greedy algorithm, which chooses to take the nearest package at each step, regardless of time requirements and other factors.
- Osqre [13]: A machine learning method, which predicts the next package at each time step through a machine learning algorithm, by considering it as a multi-class classification problem.
- DeepRoute [14]: A deep learning method, equipped with a Transformer encoder and Pointer Net decoder.
- FDNET [12]: A deep learning method, equipped with a Bi-LSTM encoder and Pointer Net decoder.
- Graph2Route [15]: A deep learning method, equipped with a dynamic graph encoder and personalized route decoder.

Table 11: Information of different selected cities.

City	Description
Shanghai	One of the most prosperous cities in China, with a large number of orders per day.
Hangzhou	A big city with well-developed online e-commerce and a large number of orders per day.
Chongqing	A big city with complicated road conditions in China, with a large number of orders.
Jilin	A middle-size city in China, with a small number of orders each day.
Yantai	A small city in China, with a small number of orders every day.

Table 12: Statistics of LaDe-D. AvgETA stands for the average arrival time per package. AvgPackage means the average package number of a courier per day. The unit of AvgETA is minute.

City	Time span	Spatial span	#Trajectories	#Couriers	#Packages	#GPS points	AvgETA	AvgPackage
Shanghai	6 months	20km×20km	70k	1,733	1,483k	2,967k	102	21.1
Hangzhou	6 months	20km×20km	71k	1,392	1,861k	3,723k	147	25.9
Chongqing	6 months	20km×20km	68k	1,494	931k	1,862k	182	13.5
Yantai	6 months	20km×20km	17k	205	206k	410k	244	11.5
Jilin	6 months	20km×20km	2k	57	31k	61k	203	16.2

Table 13: Statistics of Detailed Trajectory.

City	Time span	Spatial span	#GPS points	#Couriers
Shanghai	1 month	77km×73km	9727k	245
Hangzhou	1 months	211km×142km	17900k	443
Chongqing	1 months	403km×267km	13520k	658
Yantai	1 months	155km×114km	6616k	245
Jilin	1 months	105km×165km	2849k	613

Metrics. Following the setting in [15], the following metrics are utilized to evaluate the performance of route prediction methods:

- **KRC:** Kendall Rank Correlation [46] is a statistical metric to measure the ordinal association between two sequences. Let \hat{Y} and Y be two sequences and $R_{\hat{Y}}(i) \in [1, |Y|]$ be the position of item i in Y , a node pair (i, j) is said to be concordant if and only if both $R_{\hat{Y}}(i) > R_{\hat{Y}}(j)$ and $R_Y(i) > R_Y(j)$, or both $R_{\hat{Y}}(i) < R_{\hat{Y}}(j)$ and $R_Y(i) < R_Y(j)$. Otherwise, it is said to be discordant. To calculate this metric, nodes in the prediction are first divided into two sets: i) nodes in label $\mathcal{V}_{in} = \{\hat{y}_i | \hat{y}_i \in Y\}$, and ii) nodes not in label $\mathcal{V}_{not} = \{\hat{y}_i | \hat{y}_i \notin Y\}$. The order of items in \mathcal{V}_{in} is available, while it is hard to tell the order of items in \mathcal{V}_{not} . Still, we know that all items in \mathcal{V}_{in} are ahead of that in \mathcal{V}_{not} . Therefore, we compare the nodes pairs $\{(i, j) | i, j \in \mathcal{V}_{in} \text{ and } i \neq j\} \cup \{(i, j) | i \in \mathcal{V}_{in} \text{ and } j \in \mathcal{V}_{not}\}$. To this end, KRC is defined as:

$$\text{KRC} = \frac{N_c - N_d}{N_c + N_d}, \quad (1)$$

where N_c is the number of concordant pairs, and N_d is the number of discordant pairs.

- **ED:** Edit Distance [47] (ED) is an indicator to quantify how dissimilar two sequences Y and \hat{Y} are to one another, by counting the minimum number of required operations to transform one sequence into another.
- **LSD:** Location Square Deviation (LSD) measures the degree that the prediction deviates from the label, formulated as:

$$\text{LMD} = \frac{1}{m} \sum_{i=1}^m |(R_Y(i) - R_{\hat{Y}}(i))|. \quad (2)$$

- **HR@k:** Hit-Rate@k quantifies the similarity between the top- k items of two sequences. It describes how many of the first k predictions are in the label, which is formulated as follows:

$$\text{HR@k} = \frac{|\hat{Y}_{[1:k]} \cap Y_{[1:k]}|}{k}. \quad (3)$$

B.2 Experiment Details of Time Prediction

Methods. The following methods are chosen for experiments:

- **SPEED**, a simple speed-based method that utilizes distance/speed as the prediction value, where speed is calculated based on each worker’s history trajectories. We set the speed for workers without previous trajectories as the average speed calculated by all workers.

- LightGBM [32], a popular machine-learning method for regression tasks.
- KNN [33], a machine-learning method that trains a regressor based on K-Nearest Neighbors algorithm to predict the arrival time.
- MLP [48], a deep neural network model with 2 layers of MLPs.
- FNet [12], a deep model that predicts both route and time of unfinished tasks.

Metrics. MAE (Mean Absolute Error) and RMSE (Root Mean Squared Error), and ACC@30 are utilized as metrics. Note that delivery platforms usually provide an interval of arrival time for customer notification. Thus we compute the ratio of prediction where the time difference between predicted time and true time is less than 30 minutes (ACC@30), formulated as $ACC@30 = \frac{1}{N} \sum_{i=1}^N \mathbb{I}(|\hat{y}_i - y_i| < 30)$.

B.3 Experiment Details of Spatio-temporal Graph Forecasting

Methods. For our Spatio-temporal Graph Forecasting experimental setup, we have selected the following methods:

- **HA** [35]: HA predicts future values of a time series by calculating the mean of past observations that correspond to the same time periods.
- **DCRNN** [18]: DCRNN employs a neural network architecture that incorporates diffusion convolution and sequence-to-sequence mechanisms. This enables the model to effectively learn spatial dependencies and temporal relations within the data.
- **STGCN** [36]: STGCN is a specialized spatio-temporal graph convolution network that synergistically merges spectral graph convolution with 1D convolution. This unique combination allows the model to effectively capture correlations between spatial and temporal dimensions, enabling a comprehensive understanding of the interplay between space and time in the data.
- **GWNET** [37]: GWNET creates an adaptive adjacency matrix to capture spatial correlations and uses 1D dilated causal convolution to capture temporal dependence.
- **ASTGCN** [38]: ASTGCN leverages the power of attention-based mechanisms and a spatio-temporal convolution system to dynamically capture spatio-temporal correlations within the data. By incorporating attention, the model can focus on relevant information and effectively model various temporal properties of traffic flows.
- **MTGNN** [39]: MTGNN adopts a message-passing framework to effectively model the temporal dynamics of graph-structured data. It achieves this by aggregating information from spatially neighboring nodes and past time steps. By leveraging this approach, MTGNN captures the interdependencies and changes over time, enabling a comprehensive understanding of the data’s temporal dynamics.
- **AGCRN** [20]: AGCRN incorporates two key modules, namely Node Adaptive Parameter Learning and Data Adaptive Graph Generation, to automatically infer inter-dependencies in traffic series and capture node-specific patterns.
- **STGNCDE** [40]: STGNCDE is an innovative spatio-temporal graph neural controlled differential equation model that leverages two neural control differential equations to process both spatial and sequential data.

Metrics. To assess the performance of the above-mentioned models in spatio-temporal graph forecasting on our dataset, we employ the metrics of Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE).

C Datasheet of Dataset

C.1 Motivation

- **For what purpose was the dataset created?** Was there a specific task in mind? Was there a specific gap that needed to be filled? Please provide a description.

To meet the rising calling for datasets in the field of last-mile delivery research, we propose LaDe, the first industry-scale multipurpose real-world dataset. Compared with existing public datasets, LaDe has several merits: (1) large-scale, it consists of millions of packages, which can serve as a data foundation for learning-based algorithms in last-mile delivery. (2) Comprehensive information, the dataset contains more comprehensive features, which enables the data to support multiple research tasks. (3) Scenario diversity, it contains the data from both the package pick-up and delivery scenarios. Researchers can use the two sub-datasets to study the different work patterns of couriers in different scenarios.

- **Who created the dataset (e.g., which team, research group) and on behalf of which entity (e.g., company, institution, organization)?**

The dataset was created by Artificial Intelligence Department, Cainiao Network.

- **Who funded the creation of the dataset?** If there is an associated grant, please provide the name of the grantor and the grant name and number.

No.

C.2 Composition

- **What do the instances that comprise the dataset represent (e.g., documents, photos, people, countries)?** Are there multiple types of instances (e.g., movies, users, and ratings; people and interactions between them; nodes and edges)? Please provide a description.

The instances are packages picked up/delivered in the last-mile delivery.

- **How many instances are there in total (of each type, if appropriate)?**

There are 10,667k instances in LaDe, where an instance represents the features of a package.

- **Does the dataset contain all possible instances or is it a sample (not necessarily random) of instances from a larger set?** If the dataset is a sample, then what is the larger set? Is the sample representative of the larger set (e.g., geographic coverage)? If so, please describe how this representativeness was validated/verified. If it is not representative of the larger set, please describe why not (e.g., to cover a more diverse range of instances, because instances were withheld or unavailable).

The dataset is a sample of instances. We first randomly select several regions in a city, then collect all the packages in that region within a certain period. Note that for each region, the dataset contains all possible instances within the given time period. To further increase the diversity of the dataset, five cities with different populations are selected and recorded.

- **What data does each instance consist of?** “Raw” data (e.g., unprocessed text or images) or features? In either case, please provide a description.

The format of each instance in LaDe-P is (*package_id*, *time_window_start*, *time_window_end*, *lng*, *lat*, *city*, *aoi_id*, *aoi_type*, *courier_id*, *accept_time*, *accept_gps_time*, *accept_gps_lng*, *accept_gps_lat*, *pickup_time*, *pickup_gps_time*, *pickup_gps_lng*, *pickup_gps_lat*, *ds*).

The format of each instance in LaDe-D is (*package_id, lng, lat, city, aoi_id, aoi_type, courier_id, accept_time, accept_gps_time, accept_gps_lng, accept_gps_lat, delivery_time, delivery_gps_time, delivery_gps_lng, delivery_gps_lat, ds*).

For the detailed description of each field, please refer to Table 7 and Table 8 in Appendix A.1.

- **Is there a label or target associated with each instance?** If so, please provide a description.

Since the dataset is proposed to support multiple tasks in last-mile delivery, for easy use and flexibility, a label for a specific task is not contained in one instance. However, it is easy to construct the label for different research purposes from the raw information. Take the estimated time of arrival prediction as an example. The actual arrival time (in this case, the label) can be calculated by the difference between the *got_time* and *query_time*.

- **Is any information missing from individual instances?** If so, please provide a description, explaining why this information is missing (e.g., because it was unavailable). This does not include intentionally removed information, but might include, e.g., redacted text.

Some instances lack the courier’s location when accepting/finishing the package, i.e., *accept_gps_lng*, *accept_gps_lat*. The corresponding information is missing in the real system.

- **Are there recommended data splits (e.g., training, development/validation, testing)?** If so, please provide a description of these splits, explaining the rationale behind them.

For all the tasks conducted in the paper (i.e., route prediction, time prediction, and spatio-temporal graph forecasting), we split the data into 6:2:2 according to the time as the training set, validation set, and test set.

- **Are there any errors, sources of noise, or redundancies in the dataset?** If so, please provide a description.

No.

- **Is the dataset self-contained, or does it link to or otherwise rely on external resources (e.g., websites, tweets, other datasets)?** If it links to or relies on external resources, a) are there guarantees that they will exist, and remain constant, over time; b) are there official archival versions of the complete dataset (i.e., including the external resources as they existed at the time the dataset was created); c) are there any restrictions (e.g., licenses, fees) associated with any of the external resources that might apply to a dataset consumer? Please provide descriptions of all external resources and any restrictions associated with them, as well as links or other access points, as appropriate.

The dataset is entirely self-contained.

- **Does the dataset contain data that might be considered confidential (e.g., data that is protected by legal privilege or by doctor–patient confidentiality, data that includes the content of individuals’ nonpublic communications)?** If so, please provide a description.

No.

- **Does the dataset contain data that, if viewed directly, might be offensive, insulting, threatening, or might otherwise cause anxiety?** If so, please describe why.

No.

Does the dataset identify any subpopulations (e.g., by age, gender)? If so, please describe how these subpopulations are identified and provide a description of their respective distributions within the dataset.

No.

Is it possible to identify individuals (i.e., one or more natural persons), either directly or indirectly (i.e., in combination with other data) from the dataset? If so, please describe how.

Our data has been strictly desensitized and cannot be linked to real individuals.

- **Does the dataset contain data that might be considered sensitive in any way (e.g., data that reveals race or ethnic origins, sexual orientations, religious beliefs, political opinions or union memberships, or locations; financial or health data; biometric or genetic data; forms of government identification, such as social security numbers; criminal history)?** If so, please provide a description.

No.

C.3 Collection Process

- **How was the data associated with each instance acquired? Was the data directly observable (e.g., raw text, movie ratings), reported by subjects (e.g., survey responses), or indirectly inferred/derived from other data (e.g., part-of-speech tags, model-based guesses for age or language)?** If the data was reported by subjects or indirectly inferred/derived from other data, was the data validated/verified? If so, please describe how.

The data was observable from the courier's pick-up/delivery data on the Cainiao platform.

- **What mechanisms or procedures were used to collect the data (e.g., hardware apparatuses or sensors, manual human curation, software programs, software APIs)?** How were these mechanisms or procedures validated?

The data is collected by the software program in the Cainiao platform.

- **If the dataset is a sample from a larger set, what was the sampling strategy (e.g., deterministic, probabilistic with specific sampling probabilities)?**

We pick out several cities and randomly select regions in different cities.

- **Who was involved in the data collection process (e.g., students, crowd workers, contractors) and how were they compensated (e.g., how much were crowdworkers paid)?**

The employees in Cainiao.

- **Over what timeframe was the data collected?** Does this timeframe match the creation timeframe of the data associated with the instances (e.g., recent crawl of old news articles)? If not, please describe the timeframe in which the data associated with the instances was created.

This data was extracted from the Cainiao platform between May and November of a recent year.

- **Did you collect the data from the individuals in question directly, or obtain it via third parties or other sources (e.g., websites)?**

The data was collected from the Cainiao platform.

C.4 Preprocessing/cleaning/labeling

- **Was any preprocessing/cleaning/labeling of the data done (e.g., discretization or bucketing, tokenization, part-of-speech tagging, SIFT feature extraction, removal of instances, processing of missing values)?** If so, please provide a description. If not, you may skip the remaining questions in this section.

We anonymize the courier’s ID and package ID to protect user privacy. And we applied perturbations to the latitude and longitude points collected in the data. The accuracy of the latitude and longitude is limited to 10 meters.

- **Was the “raw” data saved in addition to the preprocessed/cleaned/labeled data (e.g., to support unanticipated future uses)?** If so, please provide a link or other access point to the “raw” data.

No.

C.5 Uses

- **Has the dataset been used for any tasks already?** If so, please provide a description.

No.

- **Is there a repository that links to any or all papers or systems that use the dataset?** If so, please provide a link or other access point.

Yes.

- **What (other) tasks could the dataset be used for?**

The dataset can be used for route prediction, estimated time of arrival prediction, spatio-temporal graph forecasting, and route optimization. See section 4.4 for more details.

C.6 Distribution

- **How will the dataset will be distributed** (e.g., tarball on website, API, GitHub)? Does the dataset have a digital object identifier (DOI)?

The dataset will be made available on the internet. There will be a corresponding Hugging Face repository associated with the dataset, and code on how to use the dataset and baseline methods.

- **When will the dataset be distributed?**

The dataset is available to the reviewers and the public along with the submission with a companion Hugging Face repository.

- **Will the dataset be distributed under a copyright or other intellectual property (IP) license, and/or under applicable terms of use (ToU)?** If so, please describe this license and/or ToU, and provide a link or other access point to, or otherwise reproduce, any relevant licensing terms or ToU, as well as any fees associated with these restrictions.

This dataset is licensed under a CC BY-NC 4.0 International License ⁴. There is a request to cite the corresponding paper if the dataset is used.

Have any third parties imposed IP-based or other restrictions on the data associated with the instances? If so, please describe these restrictions, and provide a link or other access point to, or otherwise reproduce, any relevant licensing terms, as well as any fees associated with these restrictions.

No.

Do any export controls or other regulatory restrictions apply to the dataset or to individual instances? If so, please describe these restrictions, and provide a link or other access point to, or otherwise reproduce, any supporting documentation.

No.

⁴<https://creativecommons.org/licenses/by-nc/4.0/>

C.7 Maintenance

- **Who will be supporting/hosting/maintaining the dataset?**

The employee in Cainiao will host the dataset on Hugging Face.

- **How can the owner/curator/manager of the dataset be contacted (e.g., email address)?**

The authors can be contacted via their emails mentioned in the paper.

- **Is there an erratum?** If so, please provide a link or other access point.

Not to our best knowledge.

- **Will the dataset be updated (e.g., to correct labeling errors, add new instances, delete instances)?** If so, please describe how often, by whom, and how updates will be communicated to dataset consumers (e.g., mailing list, GitHub)?

The corresponding Hugging Face page will be updated regularly.

- **Will older versions of the dataset continue to be supported/hosted/maintained?** If so, please describe how. If not, please describe how its obsolescence will be communicated to dataset consumers.

The old versions of the dataset will not be maintained. If we update the version of the dataset, we will put the specific details of the dataset update on the relevant Hugging Face.

- **If others want to extend/augment/build on/contribute to the dataset, is there a mechanism for them to do so?** If so, please provide a description. Will these contributions be validated/verified? If so, please describe how. If not, why not? Is there a process for communicating/distributing these contributions to dataset consumers? If so, please provide a description.

If others want to extend/augment/build on/contribute to the dataset, please contact the original authors about incorporating fixes/extensions.