

Tourism Forecast with Weather, Event, and Cross-industry Data

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Abstract: The ability to make accurate forecasts on the number of customers is a pre-requisite for efficient planning and use of resources in various industries. It also contributes to global challenges of society such as food waste. Tourism is a domain particularly focussed on short-term forecasting for which the existing literature suggests that calendar and weather data are the most important sources for accurate prediction. We collected and make available a dataset with visitor counts over ten years from four different businesses representative for the tourism sector in Switzerland, along with nearly a thousand features comprising weather, calendar, event and lag information. Evaluation of a plethora of machine learning models revealed that even very advanced deep learning models as well as industry benchmarks show performance at most on a par with simple (piecewise) linear models. Notwithstanding the fact that weather and event features are relevant, contrary to expectations, they proved insufficient for high-quality forecasting. Moreover, and again in contradiction to the existing literature, performance could not be improved by including cross-industry data.

1 INTRODUCTION

Substantial short-term demand fluctuations are common in the tourism industry. Therefore, tourism companies such as accommodation, transportation, catering, and leisure facilities have a vital interest in precise forecasts of the number of customers. Such forecasts fulfill at least three purposes. First, they allow efficient planning and use of resources, thereby preventing misallocation, which may manifest as either shortage or waste. Shortage can lead to overuse (exhausted staff) and queuing (dissatisfied customers). Waste occurs when unused services (empty bus rides, unconsumed meals) expire worthless according to the *uno actu* or no-stock-keeping principle. Second, precise customer forecasts allow companies to engage in dynamic pricing and revenue management. Third, forecasts can be used to inform potential customers, for instance about crowding. Precise tourism forecasts thus provide immediate economic, societal, and

environmental benefits.

A number of companies in the tourism industry like some hotels and airports can rely on advanced booking for customer forecasts. To date, most other tourism businesses base their forecasts on the intuitive expertise of responsible managers, possibly complemented with simple statistics such as some lagged number of customers or an average over a certain time period. One reason for this is that many tourism companies are Small and Medium Enterprises (SMEs) that lack financial resources and knowhow to implement sophisticated forecasting methods. While the expertise is undoubtedly powerful, the use of statistical methods can significantly improve demand forecasts and related decision making (Armstrong, 2001; Hu et al., 2004). As competition in the tourism industry grows and additional challenges appear (e.g. climate change or the Covid19 crisis), the industry is pushed more than ever to optimize operations and business models.

Several previous studies have dealt with forecasting daily customer numbers in the tourism industry, and have found significant explanatory power of weather and event features. A pioneering work (Dwyer, 1988) dealt with an urban recreation site in the Chicago area, stressing the importance of weather,

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season, and day of the week. (Brandenburg and Arnberger, 2001) addressed forecasting for a national park near Vienna, highlighting the importance of calendar effects and temperature. Ski destinations in the state of Michigan were considered in (Shih et al., 2009; Shih and Nicholls, 2011), where temperature, snow depth, holidays, and weekends were found to be relevant. Other variables known to have an effect on tourism include income, price, travel expenses, and trends (Song et al., 2003).

It is to be noted that there is no common agreement on the best quantity to measure the performance of forecasting models in tourism. A possible reason for this is that time series for different businesses have significantly different properties such as mean value, variance, seasonality, and number of zeros. Another factor may be that the economic cost of errors highly depends on the specific company under examination. Because of this, extra care is needed when comparing performance on different time series or evaluating current practices.

In recent years, the state-of-the-art in forecasting has seen a gradual shift from linear models and Exponential Smoothing (ES) to more sophisticated Machine Learning (ML) techniques. The most popular approaches include gradient boosting (Makridakis et al., 2020b), Recurrent Neural Networks (RNNs) such as DeepAR (Salinas et al., 2020), and Deep Learning (DL) models based on attention (Lim et al., 2019; Zhou et al., 2020), but also Prophet (Taylor and Letham, 2018), a model based on time series seasonal decomposition with changepoints and learnable weights for holidays, which has emerged as a quasi-industrial standard.

Massive efforts have also been conducted to understand the practical advantages of different approaches. The M4 competition considered 100,000 time series categorized in six domains and six resolutions. 61 forecasting strategies submitted for M4 were analyzed in (Makridakis et al., 2020a). The top performing method was a hybrid algorithm that combined ES and RNNs with joint optimization (Smyl, 2020). A major result of M4 was the conclusion that cross-series information is highly beneficial. The successor competition M5 focussed on 48,840 time series for item sales of stores in various locations with a 28-day forecasting horizon. M5 included explanatory variables such as calendar effects, selling prices, and promotion events. Results were summarized in (Makridakis et al., 2020b). The best performance was achieved by training 220 LightGBM models and selecting an ensemble of 6 of them for each series. Once again, models that used cross-learning from multiple series performed significantly better than the ones that

did not. Moreover, simple ML methods were found to be superior to more sophisticated ones. In the SME landscape, however, it is unfeasible to gather such a large database to train robust forecast models.

In this paper, we consider four diverse companies which operate in the tourism sector and are located in the same region of Switzerland. These destinations are of international relevance and great economic interest given the importance of tourism in this country. More precisely, we address one-day-ahead forecasting of the total number of daily customers for the ten years from 2007 to 2016. The dataset is annotated with events and weather forecast variables, and is made publicly available as part of this contribution. We claim that in this context, notwithstanding the fact that date, event, and weather features are relevant, contrary to expectations, they are not sufficient for high-quality forecasting. Moreover, we also argue that in the case at hand there is no significant benefit from a joint forecasting of multiple time series of similar nature.

The paper is structured as follows. In section 2 we describe the collected dataset, its main features and how to access it publicly. Section 3 sets up the evaluation procedure, a simple approximation of the underlying stochastic process, and the ML models we explored. In section 4 we present selected numerical results and illustrate how they support our claims. We then conclude in section 5 with more precise statements and an outlook on further steps that are needed to complete our investigation.

2 DATASET

In this section we present a novel forecasting dataset for tourism, which is made publicly available¹ as part of this contribution (Pfäffli et al., 2020).

2.1 Target Variables

The four Swiss companies we consider consist of one accommodation, two transportation, and one indoor leisure businesses, all located in the same touristic region. The customer volume data has daily resolution and features at worst minor interruptions of a few days over a common period of ten years starting in 2007 and ending in 2016. The missing values for one transportation and the indoor leisure company are masked, and the masks are available as indicator variables. For all evaluations reported in this work, forecasts on the few missing values are ignored.

¹<http://dx.doi.org/10.5281/zenodo.4133644>

Table 1: Statistical figures of the four individual datasets and the combined dataset (removing duplicate features).

Company	Features	Target mean	Target std
Accommodation	615	63	24
Transport 1	615	1106	937
Transport 2	468	2669	1654
Indoor leisure	430	1121	461
Combined	932	-	-

2.2 Feature Variables

We include date variables for calendar effects, such as e.g. the day of the week. Event data thought to be relevant for understanding customer behavior includes public and school holidays, free-time regional events, as well as promotions or revisions for the facilities under examination. The weather forecast features are provided by the Federal Office of Meteorology and Climatology (MeteoSwiss), and encode extended information about conditions in the locations of the four businesses and neighboring regions. They consist of data for temperature, sunshine, precipitation, and wind, forecasted up to 3 days in advance. The dataset thus constructed contains 562 variables both numerical and categorical. Note that the weather forecast model is updated regularly, and therefore many features do not cover the entire period. Transformed into a vector space model by means of one-hot encoding, we count 932 features, four target and two mask variables. The number of features semantically associated to each company after the transformation is summarized in table 1; additional information can be found in the download documentation.

In all experiments reported in this work, we explicitly include the targets with lags from 1 to 7 days among features. We note that the number of features is relatively large compared to the amount of available data to fit, which consists of a single number per company for each of the 3653 days in the years 2007–2016.

2.3 Publication

In the published version of the dataset, feature names are replaced with pseudonyms but descriptions are given to identify feature groups with similar meaning. The content available for download consists of

- `data.csv`, CSV format, 11.3 MB, 3654 rows and 562 columns with the time series data;
- `data-description.csv`, CSV format, 36 KB, 563 rows and 12 columns with feature name and short description, minimal statistics for cross-checking, and indicator variables that specify to which single-company datasets a feature belongs.

3 METHODS

3.1 Evaluation

In order to assess fluctuations of performance scores due to finite sample size and take full temporal dependence into account, we rely on sequential validation. More precisely, we create folds with n consecutive years for training and the following year for evaluation. We work with whole years to mitigate the influence of seasonality on the scores. We start from $n = 4$ to guarantee a sufficient amount of training data. The five folds with $n = 4$ to 8 are used for cross-validation and the one with $n = 9$ is kept out for testing.

As mentioned in section 1, the metric to evaluate the performance of predictions is not uniquely defined either by the problem or by convention. Given our time series contain a significant amount of small integer values, including zeros which may be accidental or systematic, we refrain from using precision errors. Instead, we compare results using the coefficient of determination R^2 . We observe that, up to rescaling and shift, this metric is equivalent to Mean Squared Error (MSE). When the evaluation time range is small compared to the span of past values, R^2 is also approximately equivalent to (Root) Mean Squared Scaled Error (Hyndman and Koehler, 2006).

3.2 Theoretical Bound

Customer turnout is the result of many binary (almost) individual decisions based on external conditions. Assuming these decisions obeys Bernoulli statistics, in the limit of a large number of individuals N and small turnout probability p , the outcome is described by a Poisson distribution. On the one hand, potential customers are represented by the local population and travelling tourists, which is very high compared to the turnout of all considered businesses on any given day: the limit of $N \rightarrow \infty$, $p \rightarrow 0$ with constant $\lambda = pN$ seems justified. On the other hand, it is clear that the decision process is not the same for every potential customer, the assumption of independence is violated by small groups, and saturation effects are ignored, so the model is only an approximation of reality.

Based on these considerations, the observed time series can be modelled as a Poisson process where the probability to observe a number of customers k on a specific day is given by

$$p(k|\lambda) = \frac{\lambda^k e^{-\lambda}}{k!}, \quad (1)$$

where λ is a function of the features. For a given λ , the prediction that minimizes the squared error on a given

day is the mean value of the distribution $E[k|\lambda] = \lambda$ and the expected squared error is $E[(k-\lambda)^2|\lambda] = \lambda$. In practice, even *a posteriori* when observed values are known, we do not have access to the distribution itself but only to a single sample. Using an improper uninformative prior $p(\lambda) = 1$ over the whole allowed range $\lambda \in [0, +\infty)$, we obtain $p(k,\lambda) = p(k|\lambda)$. The best guess described above then gives

$$E[(k-\lambda)^2|k] = \frac{\int_0^{+\infty} d\lambda (k-\lambda)^2 p(k,\lambda)}{\int_0^{+\infty} d\lambda p(k,\lambda)} = k+2. \quad (2)$$

This result represents the minimum forecast variance that is expected when the number of customers follows a Poisson distribution with a mean that can be exactly predicted using features. It can be used to establish a benchmark performance in an idealized case.

3.3 Models

We introduce some baselines for comparison with more sophisticated ML models, i.e. we evaluate models which always predict the same number of customers as 1, 7, 364, or 365 days before the target and take the best score as a naive baseline for each dataset. Additionally, we follow the approach in section 3.2 to obtain an estimate of performance in an optimal, idealized scenario. Finally, we gather a benchmark for an up-to-date industry-ready approach to time-series forecasting using Prophet.

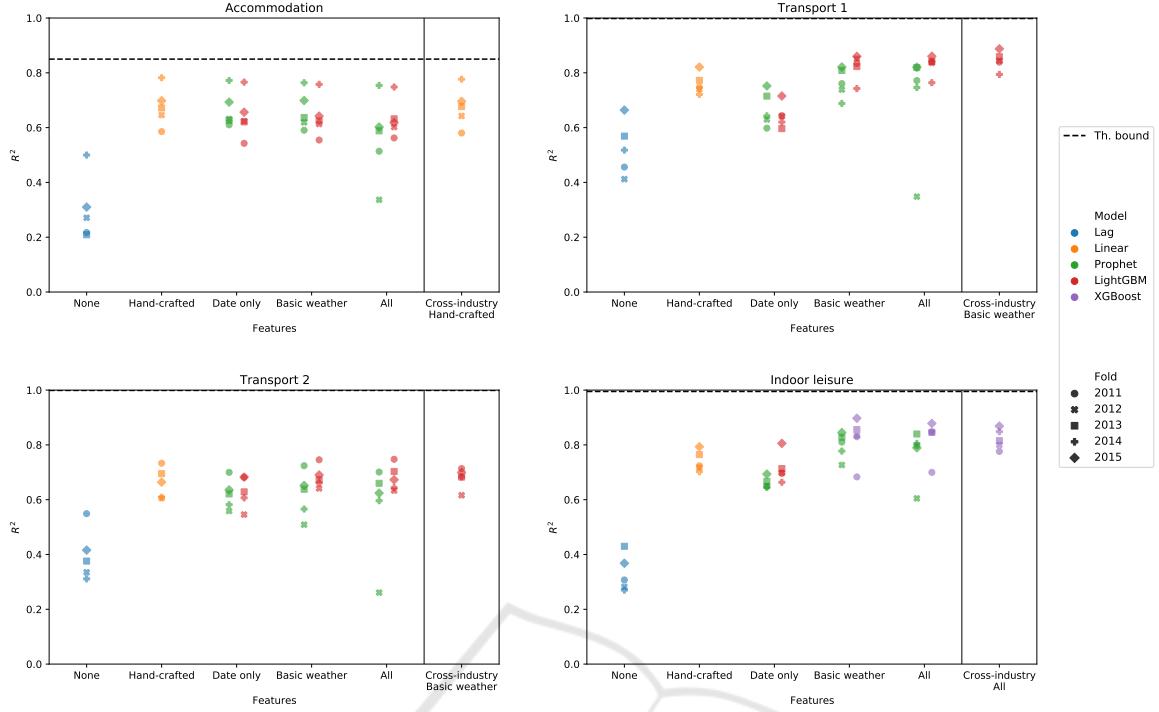
As a first non-trivial ML approach, we consider linear models fit on a hand-crafted feature set. This feature set only considers a subset of weather and event features and is based on the existing literature (see section 1) plus extensive interviews with industry representatives. It includes interaction terms to take into account that the effect of features may depend on each other, for instance weather may have a different impact on demand on weekdays compared to weekends. These interactions are constructed among date features (days of the weeks and months), and between date and weather features.

We then progressively move to more sophisticated models using all features along with regularization to control overfitting. We use MSE as loss function throughout because of the arguments outlined in section 3.1. Since it is difficult to guess which representation of the exogenous features would give the best results, pre-processing is kept to a minimum. More specifically, all features are treated on the same level, categorical variables are one-hot encoded, numerical ones are scaled between minimum and maximum value or normalized using mean and variance where appropriate, and no interaction terms are considered in this phase.

The approaches evaluated include Lasso, Ridge, and Gaussian process regression from scikit-learn (Pedregosa et al., 2011), regression trees with gradient boosting from xgboost (Chen et al., 2015) and lightgbm (Ke et al., 2017), simple dense multilayer perceptrons, RNNs with LSTM and GRU units, and RNNs with attention from tensorflow and keras (Abadi et al., 2016). For Lasso and Ridge regression we conducted a one-dimensional search over the regularization parameter. For Gaussian process regression we explored an RBF kernel with constant and white-noise terms, and a dot kernel plus white noise. We then performed a grid search to choose appropriate hyper-parameters. The dot kernel performed considerably better than the RBF kernel, but it was still not competitive with the best models. The gradient boosting family achieved a consistently good performance across folds using default values, and since preliminary experiments with settings such as tree depth did not improve scores significantly we did not tune these models any further. For the DL models, instead, we considered simple architectures with up to 4 layers and 512 units, we tried optimization with different learning rates using gradient descent with momentum and Adam, and we explored several values for L_1 , L_2 , and dropout regularization terms. We also investigated switching to Poisson log-likelihood as a loss, and generating pseudo-data with Poisson fluctuations for each epoch as an additional form of regularization. Since all options need to be evaluated for each of the four datasets and 5 different folds, we did not conduct a full grid search but limited ourselves to changing one parameter at a time. Finally, since DL models struggled to achieve consistently good scores across all folds, we did not investigate even more complex approaches such as DeepAR.

4 RESULTS

Table 2 and fig. 1 summarize the results of the baseline, the theoretical upper bound, the linear models with hand-crafted feature sets, the Prophet benchmark and the best approach among all others. The scores for Prophet and the best ML approach are reported for several feature sets: one using only the date of the observation (“date only”), one which uses all features available as described in section 2.2 (“all feaures”), and one where weather variables are summarized with a few numbers (“basic weather features”). The latter is constructed by considering forecasts only one day in advance and picking a single variable for each of the four main parameters (temperature, precipitation, sunshine/cloud cover, wind) for each location. This

Figure 1: Comparison of the R^2 sequential validation scores for selected models and feature sets.

greatly reduces the number of features to around 100. Note that 7 lagged target values are always included. For each model and company, we report the mean R^2 and its standard deviation computed on the 5 folds.

For a meaningful comparison of scores obtained using different feature sets, we also report the results of hypothesis tests for selected pairs of results. More precisely, we compare the sample score distributions over the 5 folds to detect significant differences of the population means. These distributions are expected to be significantly non-gaussian at least when R^2 is close to 1 and when there are outliers due to overfitting. Nevertheless, due to the low number of samples, we decided to perform both a two-tailed paired t -test and a two-tailed paired Wilcoxon signed-rank test. We report the corresponding p -values and the sign of the difference in table 2. The conclusions that can be drawn with these two types of tests are somewhat different in strength but identical in content.

4.1 Model Comparison

We observe that the best scores are obtained by either linear models or gradient boosting based on decision trees. They are significantly better than the baselines and worse than the theoretical bounds. Prophet is competitive with the best models if only the date is used for prediction. Since in the accommodation

case including more features is not beneficial as explained in section 4.2, Prophet remains on the same level of the other best models for this company. Note that depending on the exact feature set used, the performance difference of linear models with interaction terms, LightGBM, and XGBoost can be significant. DL models are not competitive in the settings we explored. In particular, we note that when all features are used it is difficult to introduce the right amount of regularisation that allows learning but prevents overfitting. As can be seen in the table, Prophet also sometimes struggles to deal with this issue.

4.2 Weather and Event Data

First we examine if weather and event data significantly improve predictions. To this end, we compare the best model scores obtained using all features to the ones obtained using only the date. Note that this means that sometimes we compare different models on different feature sets; however, conclusions are essentially the same if any of the two models is chosen for both feature sets. At the 95% confidence level or better, we can confirm that for the indoor leisure structure and for the two transportation companies weather and event data improves predictions. The accommodation company, instead, shows a preference for regression using only the date. While this could be a

Table 2: R^2 validation scores for single-industry forecasting using different models and feature sets. The last two sections of the table report p -values for testing the hypotheses described in section 4.2.

Company	Accommodation	Transport 1	Transport 2	Indoor leisure
Baselines				
Lag baseline	0.301 ± 0.118	0.524 ± 0.099	0.398 ± 0.093	0.331 ± 0.067
Best naive lag	1	1	1	364
Theoretical bound	0.850 ± 0.021	0.9987 ± 0.0002	0.9988 ± 0.0001	0.9949 ± 0.0001
Date only				
Prophet	0.667 ± 0.066	0.667 ± 0.064	0.613 ± 0.057	0.635 ± 0.021
This work	0.642 ± 0.081	0.643 ± 0.045	0.630 ± 0.041	0.688 ± 0.065
Best model	LightGBM	LightGBM	LightGBM	LightGBM
Hand-crafted features				
Linear model	0.677 ± 0.072	0.760 ± 0.039	0.661 ± 0.055	0.740 ± 0.038
Basic weather features				
Prophet	0.662 ± 0.069	0.764 ± 0.051	0.609 ± 0.083	0.513 ± 0.646
This work	0.634 ± 0.082	0.818 ± 0.044	0.687 ± 0.037	0.844 ± 0.033
Best model	LightGBM	LightGBM	LightGBM	XGBoost
All features				
Prophet	-0.280 ± 2.048	0.734 ± 0.133	0.521 ± 0.293	0.798 ± 0.047
This work	0.630 ± 0.075	0.825 ± 0.046	0.677 ± 0.038	0.818 ± 0.062
Best model	LightGBM	LightGBM	LightGBM	XGBoost
Hypothesis testing: all vs. date only				
t -test p -value	0.043	7×10^{-4}	0.012	0.011
Wilcoxon p -value	0.043	0.043	0.043	0.043
Relative sign	<	>	>	>
Hypothesis testing: all vs. basic weather				
t -test p -value	0.060	0.088	0.020	0.120
Wilcoxon p -value	0.043	0.080	0.043	0.138
Relative sign	<	>	<	<

signal of a different underlying stochastic process, it is also very likely that random fluctuations in smaller customer numbers make it impossible to exploit additional data.

We then investigate if it is really beneficial to use extended weather data such as weather forecasts up to three days in advance and icons displayed on weather forecast websites. For this purpose, we compare the best model scores obtained using all features to the ones obtained using basic weather data. For transport 1 and indoor leisure we observe differences which are not significant at the 95% level, while transport 2 shows a preference for basic weather data, indicating that the benefit of extra information is compensated by the drawback of more severe noise. The accommodation scores just indicate that Prophet with basic weather information is slightly superior to LightGBM with all features, but this is less relevant since Prophet can match the score just using dates.

4.3 Cross-Industry Data

According to the literature, data from different companies can be leveraged for better predictions. This is particularly interesting in the context of DL where the additional information could be used to learn more ro-

bust high-level representations of external conditions. Results of single- and cross-industry fits are reported in table 3. We observe that in practice our DL models cannot efficiently exploit cross-industry data and their performance remains inferior to other models. Note that this holds across several weight options to combine the loss functions of individual companies. Moreover, from the p -values in table 3 and the relative sign of mean differences we deduce that there is no significant performance variation when cross-industry data is included. Although only numbers for the best model–feature set combinations are reported, this conclusion holds unaltered when model and feature set are kept fixed.

5 CONCLUSIONS

In this work, we considered one-day-ahead forecasting of the total number of customers over a time span of ten years for four companies operating in the tourism sector in the same region of Switzerland. We released a public pseudonymized dataset which consists of the four time series of customer turnout plus a rich set of event and weather features that are thought to be relevant for the prediction task. We evaluated

Table 3: Comparison of the best R^2 validation scores obtained using single- and cross-industry data. The last section of the table reports p -values for testing the hypotheses described in section 4.3.

Company	Accommodation	Transport 1	Transport 2	Indoor leisure
Single-industry				
Best score	0.677 ± 0.072	0.825 ± 0.046	0.687 ± 0.037	0.844 ± 0.033
Best feature set	Hand-crafted	All	Basic weather	Basic weather
Best model	Linear	LightGBM	LightGBM	XGBoost
Cross-industry				
Best score	0.675 ± 0.072	0.845 ± 0.034	0.679 ± 0.037	0.822 ± 0.037
Best feature set	Hand-crafted	Basic weather	Basic weather	All
Best model	Linear	LightGBM	LightGBM	XGBoost
Hypothesis testing: cross-industry vs. single-industry				
t -test p -value	0.32	0.077	0.27	0.12
Wilcoxon p -value	0.22	0.080	0.14	0.14
Relative sign	<	>	<	<

Table 4: R^2 test scores computed using the best models according to sequential validation.

Company	Accommodation	Transport 1	Transport 2	Indoor leisure
Best score	0.695	0.872	0.642	0.885
Best feature set	Hand-crafted	Basic weather	Basic weather	Basic weather
Cross-industry	No	Yes	No	No
Best model	Linear	LightGBM	LightGBM	XGBoost

a plethora of different models for forecasting on this dataset, including an industry-standard benchmark, traditional ML approaches such as linear models and decision trees with gradient boosting, and a variety of DL models. We found that weather and event data do not improve forecasts for the accommodation business but are relevant for the two transportation companies and the indoor leisure facility. We observed that in our setting extended weather data is not helpful to improve predictions. Moreover, we showed that in our setting cross-industry data, such as previous numbers of customers registered by other companies in the same area and the corresponding events or promotions, does not lead to a significant improvement in forecasting. The scores on the 2016 test data are reported in table 4 for the best combination of model and feature set for each company.

We also derived theoretical bounds for scores under the approximation of Poisson statistics and observed that our best results, albeit significantly better than baselines, are still far from matching this limit. This gap has three possible explanations. First, it is possible that the generating random process is not accurately modelled by a Poisson distribution with variable mean. Second, there is a chance that essential inputs to the forecasting task such as the number of foreign tourists in the region are still missing from our feature set. Third, it is not to be excluded that the issue lies in the learning procedure and the data is not appropriately exploited by any of the approaches considered. We advocate that the mismatch between theory and the real world should be understood in order

for ML practitioners to support businesses effectively.

Finally, we observe that the utility of customer forecasts like the ones presented in this work highly depends on the actual approaches in place and the corresponding decision-making rules. Many companies base their resource allocation decisions primarily on the expertise of responsible managers, possibly complemented with simple statistics. When decision-making rules are very simple, for instance depending on whether the expected number of customers is above or below a fixed threshold, tourism companies might significantly benefit from complementing their approach with more formal models, even if these do not deliver excellent results in statistical terms. For more advanced applications, however, ML models that include information from weather forecasts, events, and other companies might still not be accurate enough to be of practical use.

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