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Using Data-Centric Platforms To Improve Demand Forecasting And Capacity Utilization For Less Digitized Multi-Site Quarrying Businesses

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Abstract

The quarrying industry, which largely consists of less digitized SMEs, is an integral part of the German economy. More than 95% of the primary raw materials produced are used by the domestic construction industry. Quarrying companies operate demand-oriented with short planning horizons at several locations simultaneously. Due to the low level of digitization and the reluctance to share data, untapped efficiency potential in data-based demand forecasting and capacity planning arises. The situation is aggravated by the fact that SMEs have a heterogeneous mobile machinery so as not to become dependent on individual suppliers, and that transport distances of over 50 kilometers are uneconomical due to high transport costs and low material values. Within the research project PROmining a data-centric platform which improves demand forecast accuracy and multi-site capacity utilization is developed. One of the core functionalities of this platform is an industry-specific demand forecasting model. Against this background, this paper presents a methodology for establishing this forecasting model. To this end, expected demands of secondary industry sectors will be analyzed to improve mid-term volume-forecasting accuracy for the local quarrying industry. The data-centric platform will connect demand forecasting data with relevant key performance indicators of multi-site asset utilization. Following this methodology, operational planning horizons can be extended while significantly improving overall production efficiency. Thus, quarrying businesses are enabled to respond to fluctuating demand volumes effectively and can increase their personnel and machine utilization across multiple quarry sites.

Keywords

Demand Forecasting; Data-Centric Platform; Capacity Utilization; Quarrying Industry; Digitization of SMEs

1. Introduction

The German quarrying industry consists largely of SMEs (small and medium-sized enterprises) with fewer than 10 employees [1]. Quarrying companies operate demand-oriented with short planning horizons at several locations simultaneously. Storing quarry mass products, such as limestone, sandstone, etc., is not economically viable, as large storage areas are required and the material properties can deteriorate due to weathering. Companies that actively focus on digital transformation and automation are still the exception in the industry today [2]. In almost all SMEs within this industry, software support is currently rather rudimentary. Most equipment and process data is recorded in analog form and only analyzed when required [3]. However, the shift towards Industry 4.0 is also affecting the mining and quarrying industry. Large international corporations are already using digital technologies on a grand scale [4]. Referred to by the term

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"Mining 4.0" or "Smart Mining", this development focuses on connecting physical mining assets and external data sources within an Industrial Internet of Things (IIoT) [5]. Due to high investment costs, many SMEs shy away from setting up a comprehensive IIoT infrastructure. Yet there is great efficiency potential for quarrying companies if multi-site operations can be controlled remotely [6]. A data-centric platform, which consolidates and evaluates site-specific data to optimize overall capacity utilization can lead to significant cost savings in the long term [7]. However, capacity utilization is subject to fluctuations caused by regional, seasonal and conjunctural demand dynamics [8]. Demand forecasting therefore relies heavily on extensive external datasets. Due to SME's heterogeneous machinery with incompatible sensor technology, platform solutions from major equipment suppliers are unsuitable [3]. Therefore, multi-site SMEs need a customized digital platform solution to monitor site-specific KPIs and adjust capacity planning to demand development. This platform can help SMEs leverage large efficiency potentials through improved forecasting capabilities and capacity planning [3].

While a data-centric platform design and a corresponding operator model have been detailed in previous publications a demand forecasting model that fits the requirements for SMEs of the German quarrying industry is yet to be published [3]. Therefore, this paper aims at establishing a methodology to create a regional demand forecasting model. In conjunction with recording current utilization metrics on the platform, demand-driven capacity planning can be improved. The forecasting model follows the methodology of Kosow and Gaßner [9] and is based on trend extrapolation of downstream industry demands. It breaks down Germany-wide demand volumes into regional and site-specific production outputs. Matched with site-specific capacity data, the forecasting model provides a decision-making basis for demand-oriented production planning. It can support SMEs with increasing production efficiency, reducing energy consumption and optimizing equipment maintenance schedules [10].

2. Theoretical background

2.1 Data-centric platforms and their application in the quarrying industry

Data sets generated, collected, structured, and stored by machines, form the basis of data-centric (B2B) platforms [11]. Data-centric platforms therefore represent a combination of interoperable, scalable, and modular technologies, that work together to meet an organization's entire data needs [12]. To this end, the connections between machines, sensors and software applications are critical to ensure effective data collection and transmission [13]. In a manufacturing environment, they form the Industrial Internet of Things (IIoT), which encompasses the integration and connection of machines, products, and processes in data-centric platforms [6]. The IIoT creates an automized interaction between machines and operating processes which can be used to increase efficiency throughout the value chain. This improves productions logistics as well as inventory management or the business processes in general [14].

The importance of developing data-centric platforms is increasing across the economy [15]. Data-centric platforms offer companies the opportunity to create new markets or tap into new customer segments. Companies also benefit from automated information exchange and services between two or more parties and gain insights from production data [16].

Data-centric platforms are already applied in the quarrying industry by large mining corporations. These platform solutions are offered by major equipment manufacturers as fleet management system for the manufacturer's own machinery [2]. Platforms that are utilizable for SMEs are not yet marketable as their heterogeneous fleets are not compatible with the software solutions and sensors [3]. Although existing platforms can provide real-time data on capacity utilization, forecasting functionalities have not yet been included. Quarrying companies incur high operating and maintenance costs. At the same time the storage of most quarry products is uneconomical. Therefore, it is important to forecast the development of demand to plan capacity utilization accordingly [17].

2.2 Demand forecasting in the quarrying industry

The German quarrying industry is characterized by a high regionality of sales markets. The material value of quarry products is very low compared to the transport costs. Thus, transport distances of more than 50 kilometers are usually uneconomical. The production volumes of the quarrying companies are therefore directly dependent on local demand [18]. Relevant external data that enables a company to forecast demand include information about consumers and market dynamics [19]. The construction sector is the largest consumer of quarry products, accounting for up to 95% of the downstream sector [1]. Seasonal effects are prevalent in the construction sector, with weather-related production declines of up to 70% during the winter months. This has a direct impact on companies in the quarrying sector, which are demand-driven and therefore have to adjust their production volumes accordingly [20].

The greatest potential of demand forecasting lies in the increase in operating efficiency and the reduction of production and maintenance costs [21]. Maintenance intervals of the machines can be calculated predictively, and personnel can be deployed in a targeted manner to ultimately reduce costs and improve production efficiency [14]. Realizing the highest possible capacity utilization with the given operating resources is essential to achieve a high economic added value [22]. Demand forecasts help with production planning and can thus contribute significantly to this.

2.3 Capacity utilization in the quarrying industry

Capacity planning is an important tool in business management, where operating resources are allocated according to the order situation and demand [17]. Modern quarrying assets are equipped with IoT sensors. They can collect a wide range of data, which is stored on the manufacturer's platform [23]. The data is then analyzed to gain information on capacity utilization. Important Key Performance Indicators (KPI's) for measuring capacity utilization comprise operating hours, fuel consumption, idle time, and production output [23].

Optimizing capacity utilization of multi-site quarry operations holds significant economic potential. Due to the regional dependency of the industry, it is important for companies to orchestrate production volumes across all sites. However, due to the low level of digitalization, the exchange of information functions only inadequately, and site data is not shared effectively. Further, there is hardly any data exchange with other operators in the industry [3]. These factors lead to over- or under-utilization of production with consequences for response time, capacity, budget, efficiency, strategy, staffing levels and maintenance. [24,25].

3. Related research and innovation contribution

Within the PROmining research project a data-centric platform concept has been developed previously [3]. The platform aims to visualize both current capacity utilization and estimate future demands to enable quarrying SMEs to monitor and plan their capacity utilization in an efficient and digitized way. Capacity planning is based on two key functionalities offered by the platform:

1) A KPI-dashboard, visualizing cross-cite capacity utilization by analyzing site-specific internal data regarding mobile assets, working hours of personnel, utility consumption and production volume.
2) A regional demand forecasting model based on trend extrapolation of downstream industry demands, which breaks down Germany-wide demand volumes into regional and site-specific production volumes.

The interplay of internal data on capacity utilization and external data feeding the demand forecasting model on the platform is shown schematically in Figure 1.

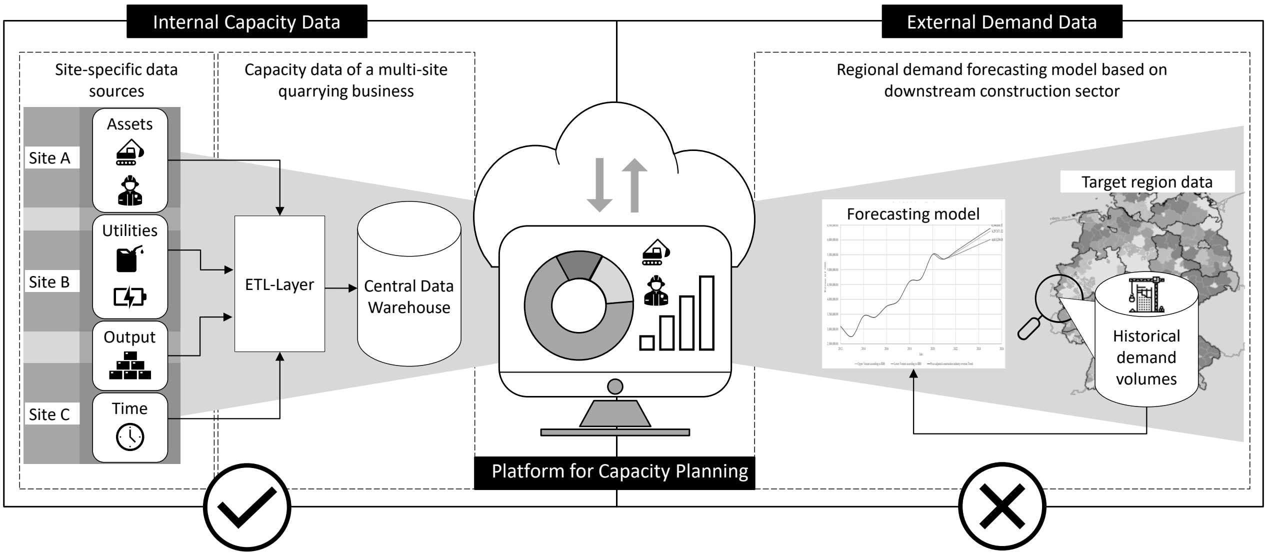

Figure 1: The data-centric platform merges internal capacity data with external demand forecast

The KPI-dashboard has been previously developed and integrated into the platform (see Figure 2).

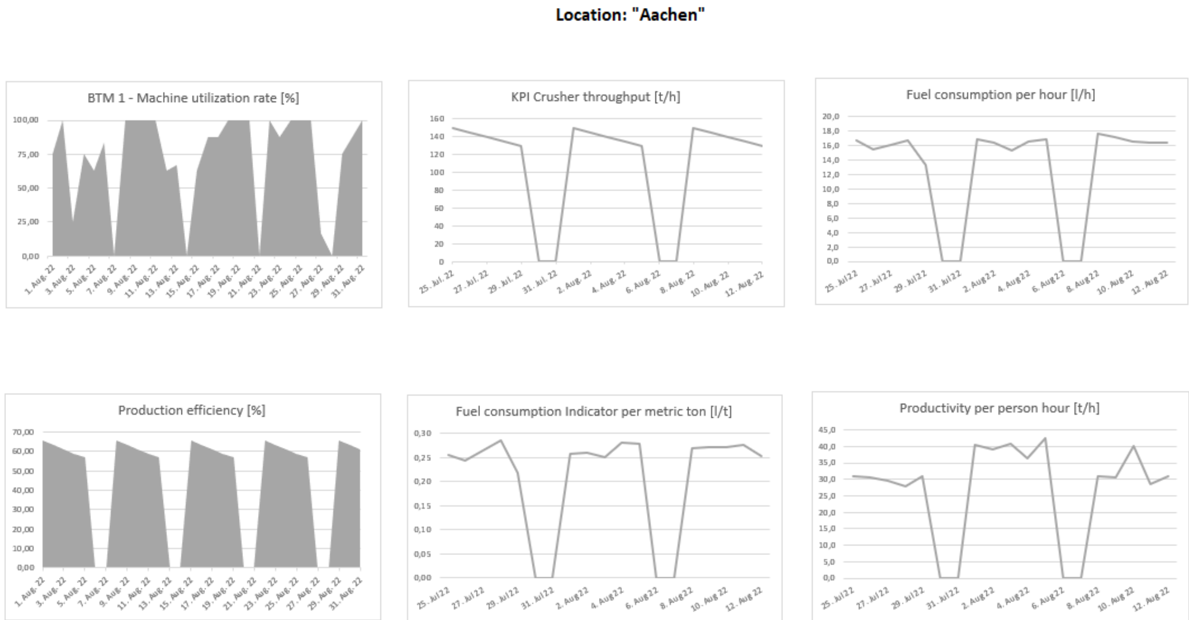

Figure 2: Cross-site KPI-dashboard of the platform

It visualizes production data of quarrying sites in the region "Aachen" as well as different KPIs, e. g. "Throughput crusher [t/h]", "Fuel consumption [l/h]", "Productivity per person-hour [t/ph]" or "Capacity of mobile operating equipment [t/h]". These indicators are used to calculate and visualize relevant KPIs, such as the production efficiency of each site, the machine utilization rate of individual production assets and machine availability. These can be used to identify unused capacities, such as conveying equipment that is not being optimally utilized.

The second key component, the regional demand forecasting model has not been implemented yet. This paper presents a methodology to create a regional demand forecasting model. Combined with current capacity utilization KPIs on the platform, this can improve future demand-oriented capacity planning for SMEs in the German quarrying industry.

4. Methodology and Study Design

To create a regional demand forecasting model to improve overall capacity utilization of German SMEs in the quarrying industry, a scenario-based analysis is conducted. This is built on a quantitative trend analysis (TIA) [9]. A scenario is defined as a presentation of possible situations in the future while trends are defined as certain developments in a specific period of time [9]. The basis of the analysis is trend monitoring, which requires extensive data collection. Identified trends and their predicted developments are being calculated with statistical methods to estimate possible future outcomes. It must be noted that a trend analysis, based solely on quantitative trend extrapolation might lack the reference to realistic future states described by qualitative factors [26]. Nonetheless, a quantitative TIA provides a practical methodology for predicting the most likely scenarios with quantifiable probabilities of occurrence [9]. Trend extrapolation requires mapping a general trend or a reference scenario [26]. Therefore, data on a series of possible future events is gathered via expert surveys or market analyses. The identified events are then projected onto the base trend in terms of their occurring probability and impact strength. Thus, individual key factors can be varied and combined with constant factors. This results in alternative progressions of the trends [9]. Figure 3 illustrates the application of a TIA based on a trend extrapolation and maps different trend developments. Up to time t0, historical data is considered for the construction of the extrapolation. Between t0 and the time of the scenario analysis, a continuation of the determined base trend (trend a) is generated. Furthermore, during this period, the TIA data is projected onto the base trendline, resulting in different trend developments (trend development b, c).

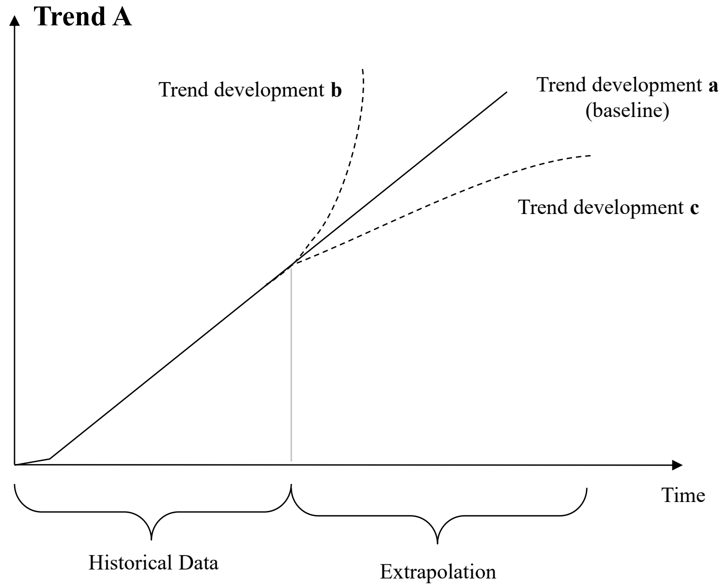

Figure 3: Schematic representation of a trend impact analysis [9]

5. Results

5.1 Methodology for establishing a regional demand forecasting model

In the light of the increasing uncertainty of societal and natural circumstances, future-oriented decisions and capacity planning are becoming more and more important [9]. As database for the demand forecasting model, external data of the downstream construction industry was used. The development of the regional demand forecasting model follows the methodology of Kosow and Gaßner and can be divided into five steps which are shown in Figure 4.

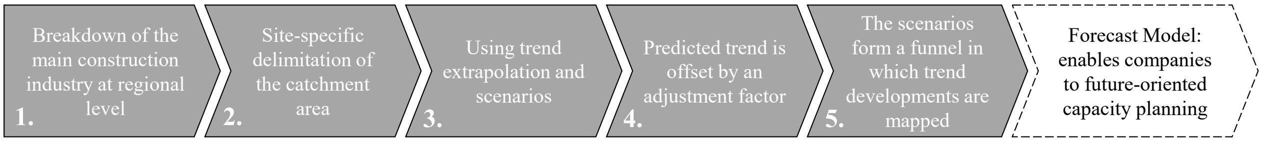

Figure 4. Methodology for establishing the forecasting model

The downstream construction industry is the most important customer segment of the quarry industry, accounting for 95% of the purchase volume. The working hypothesis is, that fluctuations in demand in the construction sector lead directly to comparable changes in production volumes in the quarrying industry. Further it is assumed that construction sector sales figures act as an indicator of quarrying industry production volumes. Thus, it is possible to draw conclusions about the regional demand for quarry products based on the turnover of regional construction companies.

The following step is the delimitation of the site-specific catchment area of a company. Due to high transport costs, the relevant radius of deliveries is limited to a maximum of 50 kilometers. Aachen, Germany was studied as an example region. 10 municipalities border the Aachen region that meet this requirement.

After that, the turnover of the construction industry in the above-mentioned area was examined and a trend extrapolation was carried out. The total sales revenues of the regional construction sector were examined on a monthly and yearly basis and projected onto the regional quarrying industry. A regular drop in demand of up to 70% during the winter months is noticeable. This is due to the difficult weather conditions that the construction industry faces during this period [20]. In a year-on-year comparison, however, this temporary decline was negligible due to its regularity. The possible development trends in the construction industry were analyzed separately by the BBS-Study [27]. The analysis distinguishes four main areas of activity in the construction industry (see Table 1), which can be mapped separately for the scenarios:

Table 1: Scenarios for the four areas in the construction industry

Calculation of the two scenarios according to BBS (change compared to 2020)	**Upper variant 2025**	**Lower variant 2025**
Construction volume in new residential construction	9.10%	5.70%
Volume of new non-residential construction	13.90%	5.80%
Construction volume in existing buildings	18.30%	13.00%
Construction volume in civil engineering	15.50%	11.80%
Mean value of the percentage change in the construction volume	**14.20%**	**9.08%**

Economic developments in the four fields of activity mentioned above are estimated using leading indicators for overall economic and demographic development [27]. In line with the different underlying data, a distinction is made between a lower and an upper variant which is shown in Table 1. These variants are applied to the overall revenue of 2020 to represent an upper and lower boundary in 2025. The various scenarios form a funnel in which a range of possible trend developments is mapped so that companies can adjust their capacity planning to the probable change in demand.

In the fourth step the predicted trend is offset by an adjustment factor which is based on a study by the German "Bundesverband Baustoffe – Steine und Erden e.V.": *"In order to take into account, the described changes in the demand for raw materials in the construction industry and the relevant economic sectors, an adjustment factor of -1.75 percentage points per year is applied when estimating the future demand for quarry products in Germany. This includes the difference in the change in the real production value or the production quantity (tonnage). "* [27]

In the following, the trend extrapolation result is shown for the region Aachen resulting from the steps described above. The turnover of the construction industry from 2012 to 2021 was analyzed for the ten different municipalities in the transport radius of Aachen. Based on the data, a trend extrapolation was carried out up to the year 2025, whereby the sum of the turnover of the 10 locations was extrapolated. The resulting value of 6,507,904.47 TEUR was reassessed with an adjustment factor of -1.75 percentage points. The predicted price-adjusted construction-related turnover for a quarrying company in Aachen 2025 amounted to 6.297.871,32 TEUR. To consider additional scenarios the upper and lower variants of the expected change for 2025 in the four areas of the construction industry (see Table 1) were offset against the overall construction turnover in 2020. The result of the upper variant is 6.394.016,15 TEUR and of the lower variant is 6.015.239,18 TEUR. All three scenarios are shown below in Figure 5.

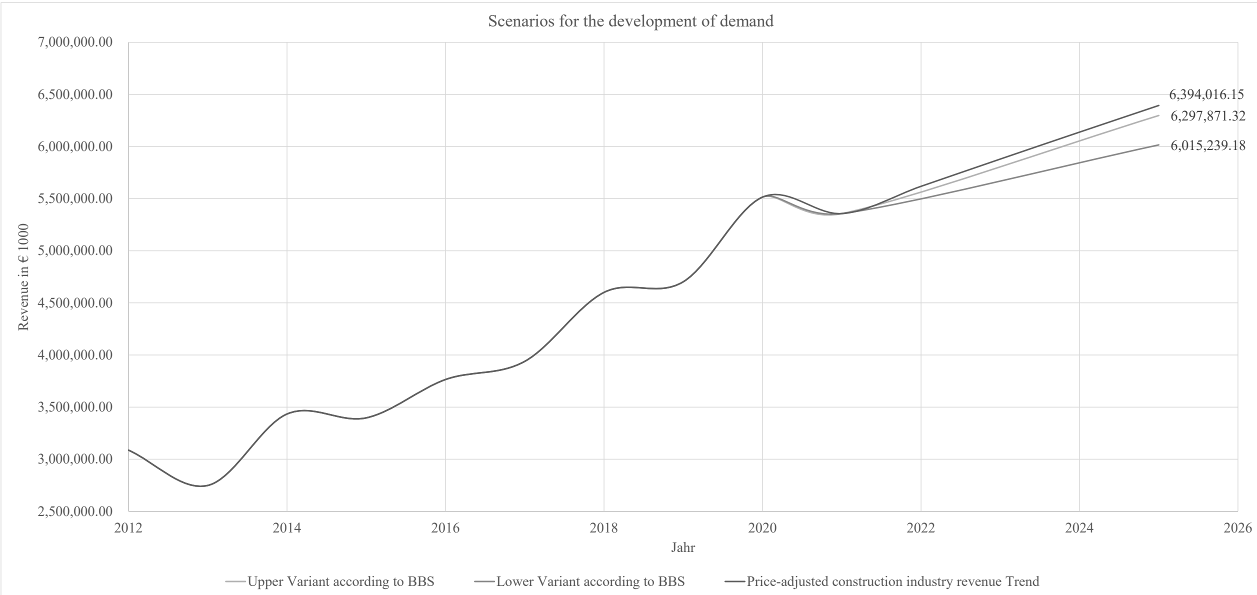

Figure 5: Trend extrapolation and scenarios for the development of demand in the quarrying industry

The different scenarios form a result funnel encompassing a range of possible trend developments. These regional scenarios, in combination with the recording of internal capacity utilization, offer quarrying companies in Aachen the possibility of carrying out improved future-oriented capacity planning.

6. Conclusion

A methodology for developing a regional demand forecasting model was explained using the example of the quarrying industry in Aachen. The approach of developing a regional demand forecasting model provides a five-step process for SMEs in the quarrying industry. As one of the main functionalities of the presented data-centric platform the regional demand forecasting model can help SME improve their decision-making on capacity utilization.

Studies show that the industry is subject to strong fluctuations due to regional, seasonal and conjunctural demand dynamics and still has some efficiency potential open due to the low level of digitalization. While the methodology for building a regional forecasting model can provide guidance, concrete input data is essential for improving the accuracy of the resulting model. With this in mind, it is necessary to understand what factors the four construction industry sectors studied are directly dependent on and how. In addition, it would be interesting to analyze how regional demand differs with respect to specific categories of quarry products, as price differences and production volumes can vary significantly. With additional data sources, more accurate multivariate forecasting methods can certainly be applied. However, since demand forecasting is hardly used within this industry, even a linear regression method considering only the most important influencing factors, could offer great practical benefit.

It can be assumed that this methodology can be transferred to structurally comparable industries with a low level of digitization as well. However, the underlying hypotheses for demand forecasting rely on the heavy dependency of the regional quarrying industry and construction sector. Therefore, the forecasting methodology needs to be validated and tested within the quarrying industry first before being adopted in other industry sectors.

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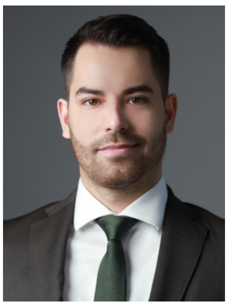
Biographies



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