Research Assessment Exercise 2020
Impact Case Study

University: The Hong Kong Polytechnic University (PolyU)

Unit of Assessment (UoA): 11 Mathematics and Statistics

Title of case study: Improving fabric manufacturing efficiency through a hybrid quality rate prediction model

(1) Summary of the impact

PolyU researchers' development of a hybrid statistical model has directly enabled *Esquel*, a global textile manufacturer based in China, to save over HK$2.5 M in production costs and reduce fabric wastage by 120,000 yards annually in addition to significant environmental savings, including a 375 ton reduction in greenhouse gases, all while saving manpower. *Esquel*, which produces 110 million shirts per annum, states that the PolyU software has "*largely transformed (a) vital step*" of the manufacturing process, and more broadly "*shifts the paradigm and changes the mindset of our workforce*" regarding the future digitalisation of the manufacturing process.

(2) Underpinning research

Each year Esquel, a global textile manufacturer, suffers delivery shortages or fabric wastage due to under- or over-estimation when fulfilling orders. The company sought to mitigate this loss through data-driven efficiencies as part of a company-wide strategy to start using big data to modernise their business.

The process of weaving or knitting fabric from yarn inevitably results in manufacturing defects in the finished textile. When *Esquel's* customers request 'A-Grade' fabric, they want only the highest quality product so when fulfilling orders, *Esquel* must estimate how much fabric to produce and include a percentage of wastage that will not make the grade.

Dr Daihai He and Dr Binyan Jiang from The Hong Kong Polytechnic University (PolyU) undertook research to find a statistical learning approach to accurately predict wastage, and produced software to more accurately plan manufacturing jobs. This project was initiated in December 2017 and the results delivered to Esquel in June 2018.

The prediction is built on a hybrid statistical model, relying on Dr. Jiang's recent research in high dimensional discriminant analysis [1, 3, 4] and high dimensional regression [2]. A fairly uncommon prediction problem in statistical research, the response variable is a one-inflated fractional variable, as many jobs can reliably produce 100% A-Grade fabric. Additionally, the number of variables in the data set is very high, creating further challenges in both feature and interaction detection as well as numerical implementation. To incorporate these complex structures into the data, the PolyU team proposed a hybrid model that involves discriminant analysis and regression under high dimensionality.

The first task of discriminant analysis is to determine whether the job is a simple one likely to produce no wastage, or a complicated one. Their algorithm uses data from previous years and seeks the best quadratic functions of the high dimensional features that can produce accurate classification results.

The second step is a regression with high dimensional features. Similar to the first step, the algorithm seeks the best linear projections with consideration of possible interactions between the features.

To conduct model selection and estimation simultaneously, penalization methods were used to estimate the hybrid model. In particular, techniques and algorithms from Dr. Jiang's current research works [1, 2] were used in the hybrid model's estimation and implementation in this project. Dr. Jiang developed an efficient and direct estimation method for obtaining a quadratic classification rule under high dimensional assumptions [1]. This technique was used to solve the classification part of the hybrid model. Similarly, in a recent paper [2], Dr. Jiang developed an efficient method for high dimensional regression with interactions. He used a version of this to handle the regression part of the hybrid model. Using his programming expertise, Dr. He further developed the user-friendly software now used by the Esquel Group's factories.

(3) References to the research

[1] B. Jiang, X. Wang and C. Leng (2018) A direct approach for sparse quadratic discriminant analysis. *The Journal of Machine Learning Research*. 19(1), 1098-1134.
[2] C. Wang, B. Jiang and L. Zhu (2019) Penalized interaction estimation for ultrahigh dimensional quadratic regression. Accepted in *Statistica Sinica* and publicly available *arXiv preprint arXiv:1901.07147*.
[3] C. Wang and B. Jiang. (2018) "On the dimension effect of regularized linear discriminant analysis." *Electronic Journal of Statistics*. 12(2), 2709-2742.
[4] B. Jiang and Z. Chen and C. Leng (2019) Dynamic linear discriminant analysis in high dimensional space. Pre-print in *Bernoulli* and publicly available *arXiv preprint* (version 1 in 2017) *arXiv:1708.00205*.

(4) Details of the impact

PolyU's Faculty of Applied Sciences and Textiles - of which the Department of Applied Mathematics is a part - have fostered strong links with *Esquel* over a number of years, signing a memorandum of understanding and making academic visits to understand the company's research challenges. In late 2017, *Esquel* requested a data-driven process improvement that could reduce fabric wastage and costs due to inaccurate production estimates. The Department of Applied Mathematics then worked with *Esquel* to establish a collaborative research project, conducted between December 2017 and June 2018.

With around 55,000 employees, The *Esquel Group* is one of the world's leading premium cotton shirt producers, producing shirts for their own brands, and for many leading fashion brands, including *Ralph Lauren*, *Tommy Hilfiger*, *Brooks Brothers*, *Hugo Boss*, *Nike* and *Muji*. With an annual capacity of 23,000 tons of knit fabric and 140 million yards of woven fabric, *Esquel* sew and finish these fabrics into 110 million woven and knit shirts annually [A, B].

Predicting the A-Grade fabric rate plays an important role in daily fabric manufacturing at the *Esquel Group's* woven mill factories. To fulfil an A-Grade fabric order, imperfections must be assumed in some of the fabric produced, and an additional percentage produced to cover this wastage. Overestimating that percentage, wastes time and resources in producing that fabric. Underestimating it is even more costly, as resetting an entire production line job to top-up an order is expensive and affects scheduling as time must be found to re-run a job. A good prediction rate reduces unnecessary waste and raw material preparation costs at the early input calculation stage and ensures more dependable work schedules.

PolyU's Dr He and Dr Jiang conducted extensive on-site research at *Esquel's* Guangdong manufacturing facilities, the site of all their woven mill factories which employ over 20,000 workers. The developed software was delivered to the company in June 2018 and immediately implemented in all their woven mill factories. The *Esquel Group's* Vice Chairman claims the software *"largely transformed this vital step of the pre-production process*" instantly [C].

Reduced production costs and improved manufacturing efficiency

Feedback from *Esquel* confirms that the PolyU model predictions outperform predictions based on traditional methods. This not only reduces production costs but also improves product planning efficiency by making purchase and stock of raw materials more accurate, and solidifying job scheduling. The model is *"applied on all production job orders [at the woven mill factories], which produces over 9 million yards of fabric per month*" [C]. The model marked a fabric manufacture efficiency improvement of 0.11%, translating to savings of around 120,000 yards of fabric and nearly HK$2.5M in production cost savings annually. In the 15 months between implementation and the end of this RAE period, around 150,000 yards of fabric have been saved, at a production cost saving of over HK$3M.

Environmental impact

Sustainability is one of *Esquel's* core values and an integral part of their corporate culture. The main pollutants from fabric manufacturing are industrial wastewater and waste gas. Our project significantly reduced both industrial pollutants and energy costs. *Esquel* conducted tests to evaluate the environmental savings translated from the saving of around 120,000 yards of fabric per year [D]. These figures are as follows:

Environmental benefits	**Per annum**	**During RAE period**
Savings in electronic energy (kWh)	201,670	252,087
Reduction in wastewater (tons)	2155	2694
Reduction in exhaust emissions (kg)	6.2	7.75
Reduction in greenhouse gas (tons)	300	375
Reduction of Chemical Oxygen Demand (COD) (tons)	25.9	32.4

Better interpretability and adaptivity

Our approach is model based and is dynamically updated, providing *Esquel* with real-time improvements to the algorithm as it learns from previous jobs. Our model has identified important features and interactions that would affect the A-Grade rate, providing the company with valuable information about quality production, as described by the Vice Chairman:

> "*With the research team's advanced data processing technique as well as its expertise on big data, the intelligent model takes into account a wide range of factors, including but not limited to pattern, color, finishing methods, stretch type, warp density and warp yarn type and count. It also allows us to conduct calculations per job order, since the model is able to deliver an automatic estimation rounded to the nearly hundredth percent within seconds upon the input of above parameters*" [C].

Reduction of manpower

Our method is data driven and our software can be easily and efficiently implemented. The traditional prediction method that *Esquel* had been using relied on both professional experience and a time-consuming empirical references procedure based on past years' data. A manual process was undertaken to update the parameters once a year, a task that could take two full days to complete. Our software eliminates this process, obtaining predictions within seconds, enabling automatic data processing and analysis with little manpower.

In 2017, *Esquel* completed nearly 26,000 jobs. Each of these now has its own estimate, completed automatically within seconds. Under the previous system, workers had to look up an estimate based on the annual calculation, a small task, but one completed on average 70 times a day.

"Shifting the paradigm" to support changing innovation culture at Esquel

Esquel report significant benefits from the project in more qualitative ways. Traditional industries rely heavily on manpower, and often do not efficiently utilize the information hidden within historical data. The *Esquel Group* would like to pursue 'digitalisation' to revolutionise their manufacturing technology. This project's statistical model is the first data analytic model built following their new digitalisation policy. *Esquel* describes how:

> "*the success in our collaboration with PolyU on this intelligent model … showcases how advanced processing of quality data could bring business results and sheds light on the potential of big data and data analytics. It supports Esquel's strategy of integrating people and technology. It shifts the paradigm and changes the mindset of our workforce"* [C].

To further support and build their staff's capacity to use big data, *Esquel* invited our research staff to deliver data analysis training to technicians from different *Esquel* factories. A recent training workshop, conducted in May 2019 and serving 42 participants, received positive feedback [E], with participants noting:

> "*(it has) broadened my horizons on data analysis, and equipped (me) with some useful tools for future data mining and analysis tasks*"

> "*Prediction using statistical and machine learning approaches are something we are not very familiar with. The workshop train(ed) us in using new methods and tools*".

Following the success of this project on quality rate prediction, the *Esquel Group* has already engaged our Department of Applied Mathematics in further research collaborations. A collaborative research project on predicting the pre-shrink parameters in the fabric finishing process started in April 2019, and the company is collecting and cleaning more data from other production lines, so as to prepare for further collaborations with PolyU.

(5) Sources to corroborate the impact

[A] Information about Esquel Group from their website: http://24-7nos.esquel.com/introduction
[B] Article about Esquel Group from MIT HK Innovation Node website (archived July 2019)
[C] Supporting letter from Vice Chairman, Esquel Group, May 2019
[D] Email evidence from Vicky Chen, Senior Manager, Esquel, August 2019
[E] Internal report of the training program conducted at Esquel in May 2019