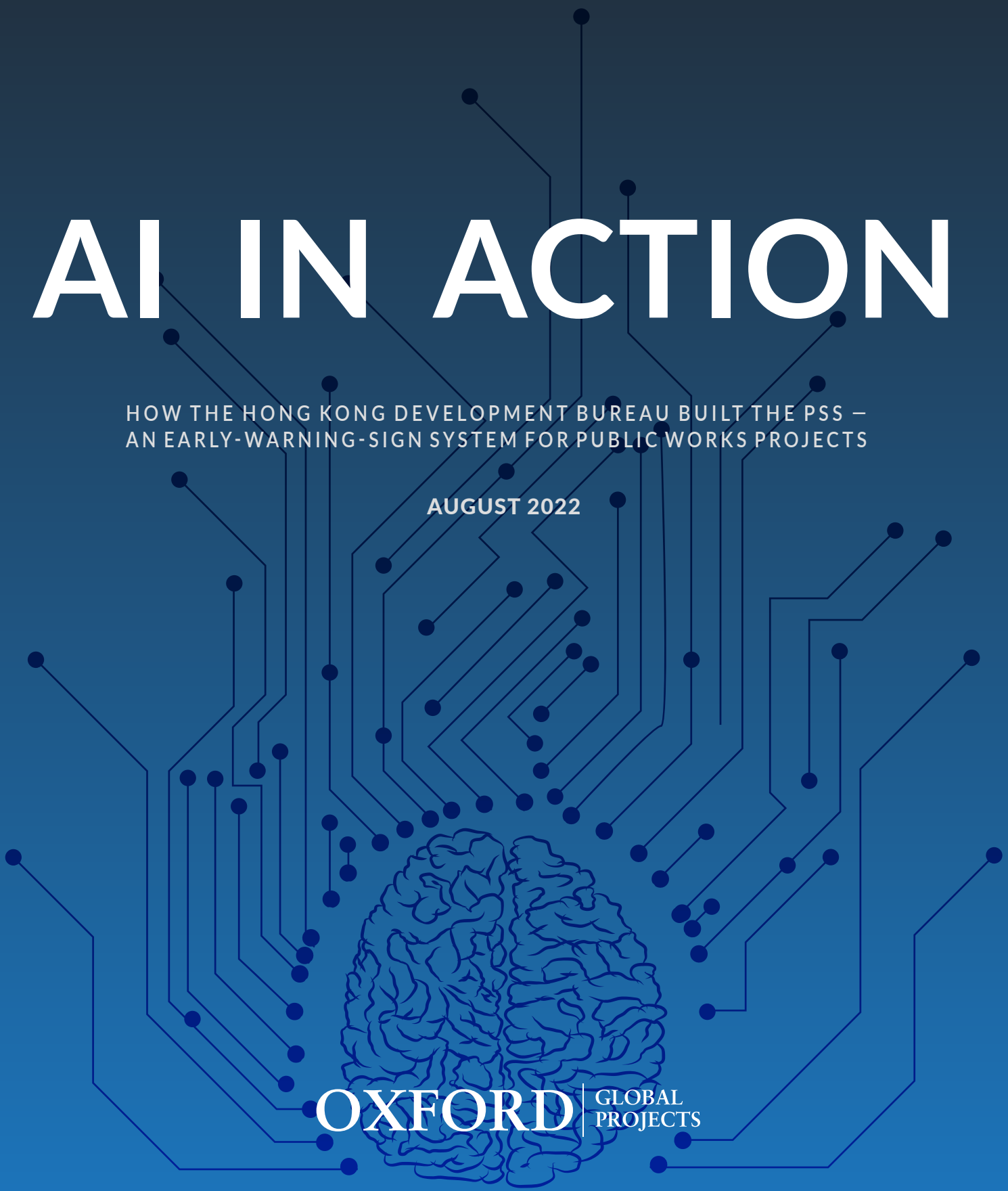
CENTRE OF EXCELLENCE
FOR MAJOR PROJECT LEADERS

AI IN ACTION

HOW THE HONG KONG DEVELOPMENT BUREAU BUILT THE PSS – AN EARLY-WARNING-SIGN SYSTEM FOR PUBLIC WORKS PROJECTS

AUGUST 2022



OXFORD GLOBAL PROJECTS

"Hong Kong has a proud reputation as one of the world's leading global cities and has been ranked one of the top regions in infrastructure by the World Economic Forum.
To support the sustainable development, we strive to invest progressively in capital works projects for tomorrow's Hong Kong.
Through the Project Strategy and Governance Office we provide the thought leadership that will help us achieve the Construction 2.0 agenda - 'innovation', 'professionalism', and 'revitalization' for the construction industry of Hong Kong.
A key building block of Construction 2.0 is the use of digital cutting-edge tools in design, planning, construction and oversight of projects.
I welcome the adoption of Artificial Intelligence to help all major project leaders across different sectors take Hong Kong's construction industry to new heights."

Ir Ricky LAU Chun-kit
Permanent Secretary for Development (Works), Development Bureau
Hong Kong SAR Government

"Capital works projects around the globe face two key challenges: the Iron Law of major projects and the flatlining productivity in construction. Historically, major projects have been over budget, over schedule, under benefits; over and over again. We need to overcome this Iron Law.
Secondly, construction productivity has not improved in the last 70 years for which data is available. Hong Kong is no exception to this.
I am honoured and excited to work with the Project Strategy and Governance Office of the Hong Kong Development Bureau to make the Construction 2.0 agenda a reality, overcome the Iron Law and improve construction productivity in Hong Kong.
Cutting-edge digital tools are key elements of this journey. Digital tools will revolutionize construction as they have the world of information technology.
I am delighted about our collaboration which brings these tools to Hong Kong. I am proud that in this report we are able to share our innovations with you for the first time."

Prof Bent Flyvbjerg
First BT Professor and Inaugural Chair of Major Programme Management, Oxford University, Villum Kann Rasmussen Professor and Chair, IT University of Copenhagen, and Chairman of Oxford Global Projects

EXECUTIVE SUMMARY

Hong Kong has a large volume of construction works currently taking place; this will increase further and faster in the coming years.

Hong Kong's projects typically come in 15% under budget. However, ten per cent of local projects over-run their budgets, with a total overspend of eight percent.

Some flagship projects have over-run their budgets and completion dates, causing public embarrassment.
It is crucial to get these cost and schedule estimates under control in order that the booming infrastructure environment in Hong Kong can flourish to its potential while carefully monitoring costs and performance.

We investigated whether Artificial Intelligence (AI) can play a part in accurately predicting these outcomes and identifying ahead of time when a project is going off track, allowing early intervention.

The large volume of projects in Hong Kong needs to be monitored collectively, with a system that allows leaders to focus their efforts on the projects most likely to fail. An automated system simplifies this process, and in our studies was found to be as accurate as the best-in-class human cost estimates.

High quality data is available in Hong Kong, and we studied a total of 2,700 years of combined construction activity and HKD 450bn in construction spent to trial this innovative project management approach. We unexpectedly discovered, however, that the AI needs only a very small amount of data in order to make good predictions.

WE BELIEVE THESE EARLY FINDINGS WILL INFORM A NEW APPROACH TO PROJECT PERFORMANCE MONITORING AND LEAD THE WAY IN CAPITAL WORKS PROJECTS INTERNATIONALLY.

THE CHALLENGE

HK PROJECTS

Hong Kong expects project spending to increase by 42% between 2021 and 2031. The expected annual expenditure will reach up to HKD 325bn by 2031.
However, these projects are not without their problems.
To spot challenges early, the Project Strategy and Governance Office established a system to support supervision and governance of projects by providing early-warning signals to senior leaders of projects that are at risk.

Projects are used to deliver the most significant initiatives in the world; from the Olympics, the artificial island of Lantau, to the International Space Station.

One of the challenges currently faced by project leaders and investors is that projects do not perform well.

They underperform in terms of execution, with significant cost and schedule overruns. 50% delays are common.

Our research has shown this woeful underperformance is so consistent that we've coined the iron law of megaprojects: they are 'over budget, over time, over and over again'.

This poor performance is not a recent phenomenon: it has been fairly consistent for over 70 years. It is also common to different countries, sectors and delivery in the private and public sectors.

The scale of projects has been increasing for decades. The largest megaprojects have budgets that match the gross domestic products of the largest countries.

The GDP of Hong Kong in 2020 was USD 347bn, a similar amount to the budget for China's high speed rail of USD 300bn and the USA's joint strike fighter (USD 400bn). This large scale means that it is crucial for the money spent on projects to be better managed.

The impacts of funds of this size being mismanaged can be felt on a national and even international scale. Over the period 2008 to 2017, per-

42%

Increase in HK construction investments by 2031

325bn

Forecasted annual spend in Hong Kong Costruction by 2030/31

3rd

Hong Kong is the 3rd most expensive city to build in the world

548

Total of on-going Category A projects in 2019-20

formance on Government projects under the Capital Works Programme has generally been to a good standard, particularly from a budget perspective. Although certain projects required additional funding owing to project specific circumstances, the majority of approved projects were delivered at or under the original Approved Project Estimates (APE).

Additional funding was required in approximately 10% of the projects and the amount represented some 8% of the total provision of these projects.

Also of importance, this period of time was particularly active for the Industry, with approximately 850 Category A projects having their final accounts settled. In terms of cost, the original APE of these projects totalled approximately HKD 240bn as compared with cumulative final accounts of approximately HKD 210bn – leading to an overall surplus of HKD 30bn.

Effectively, this means the surplus generated at the portfolio level was more than able to offset the cost overruns incurred by a select number of projects.

To reinforce the positive nature of this performance, Professor Bent Flyvbjerg of the University of Oxford pointed out that Hong Kong is better than many other regions when it comes to project cost estimation, based on his findings in a study covering over 100 international jurisdictions.

Megaprojects are those that come with high levels of procurement, design and/or construction complexity as well as scale. They typically take multiple years to implement and often involve high levels of risk to the participants involved. Unfortunately, a number of complex megaprojects in Hong Kong have suffered from underperformance in the form of delays, cost overruns and/or quality failures in recent years. These incidents have been well documented through extensive media coverage – leading to reduced levels of public confidence in the industry.

The early stages of a project are crucial and can set the tone and influence its efficacy. One of the challenges of project performance is the sensitivity to timescales in taking corrective action. The later such actions are undertaken, the harder and more resource intensive it is to rectify problems.

However, it is not always easy to identify risky projects before things have gone wrong and they require substantial and costly remedy. The Construction Industry Council estimates that construction expenditure will increase in real terms by up to 42% to HKD 325bn, compared to 2021. The Development Bureau of the Hong Kong Special Administrative Region has launched their vision for Construction 2.0 to support effective delivery.

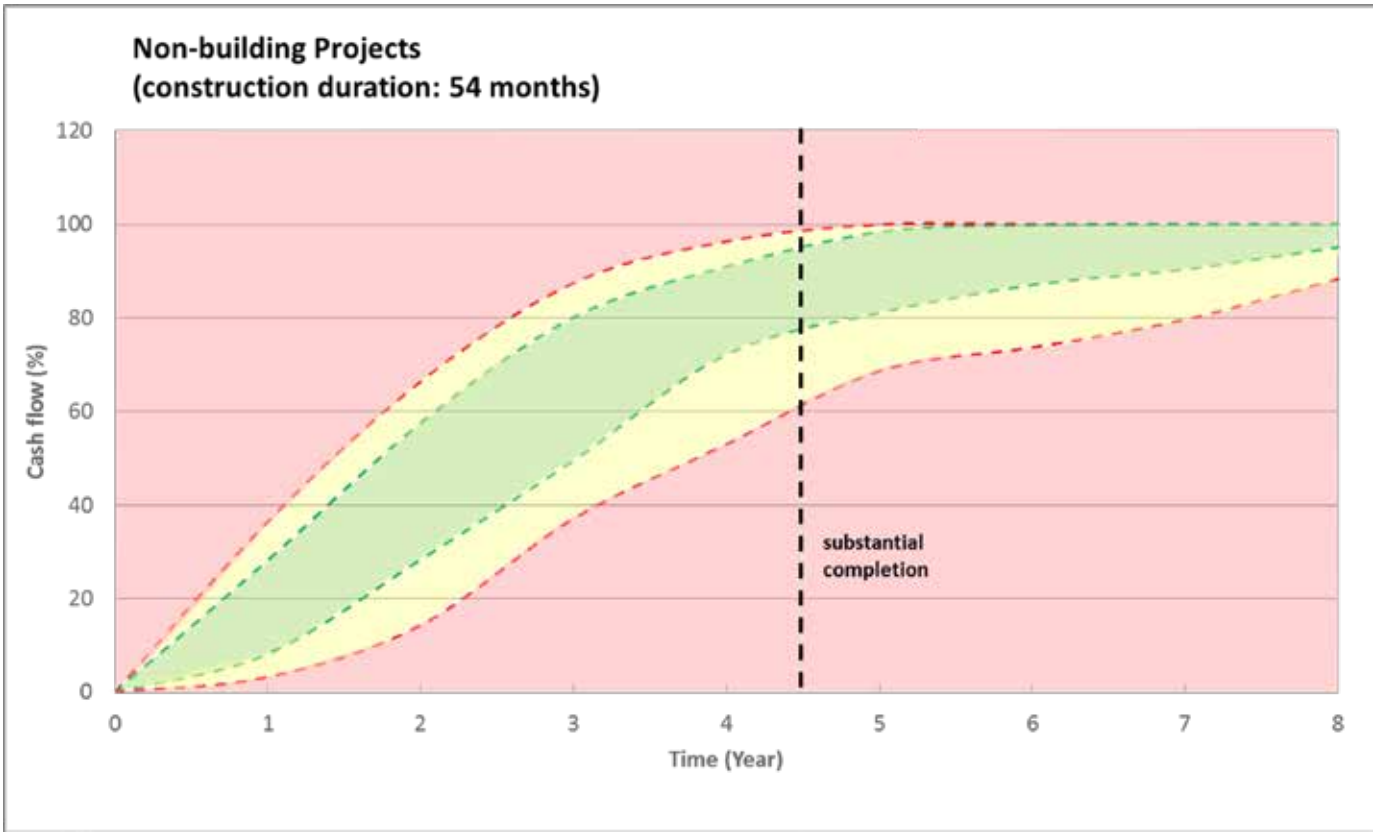
A key policy objective of the Development Bureau is 'to ensure the effective planning, management and implementation of public sector infrastructure development and works programmes in a safe, timely and cost-effective manner and to maintain high quality and standards.'

In order to do this, it is vital for senior managers to notice problems and ensure efficient, effective and timely intervention when necessary. However, senior managers lack the daily and deep involvement in their projects. They need the right monitoring tools and early-warning -sign systems to help them in their project supervision.

THE EXISTING SYSTEM

EARLY WARNINGS

A WEB-BASED MONITORING SYSTEM BASED ON CASHFLOWS OF HISTORIC PROJECTS



The Development Bureau uses the PSS, or Project Supervision System, to monitor capital works projects and provide early-warning signals to senior management. The PSS is a web-based application comprising a series of standardized project cashflow graphs.

The graphs are based on the past cashflows of capital works projects. The PSS covers different categories for building and non-building projects with various construction durations.

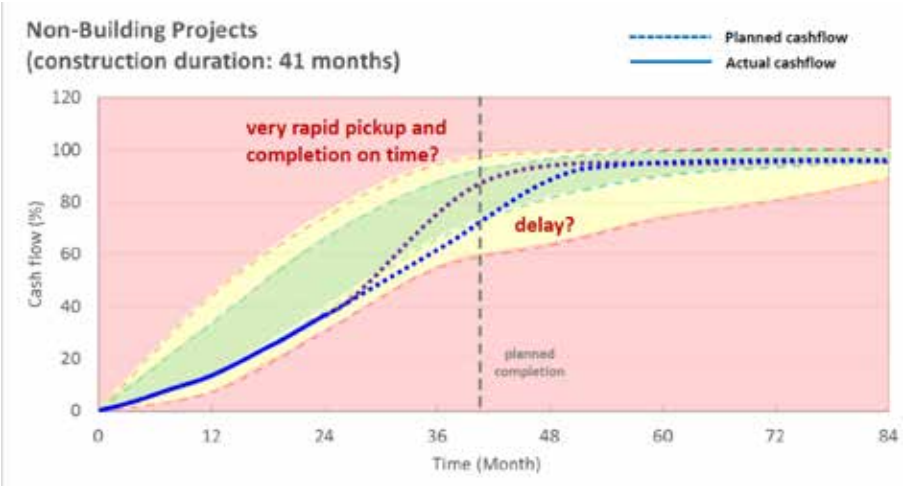
All active projects submit their actual cashflows to date and their planned cashflows for the remainder of the project. The PSS uses this information to identify any unusual patterns.

There are 3 types of patterns which then trigger different follow-up actions.

First, normal performance. The project cashflow falls within the green zone. There is no follow-up action for projects with normal performance. The data of these projects will be stored for future use and refinement of the system.

Second, yellow performance raises an alert. The project cashflow falls within the yellow zone, meaning heads of departments need to review these projects. The review takes in the risk of cost overrun and programme delay. The heads of departments are responsible for the project assessment and, if necessary, for the planning and implementation of appropriate recovery measures.

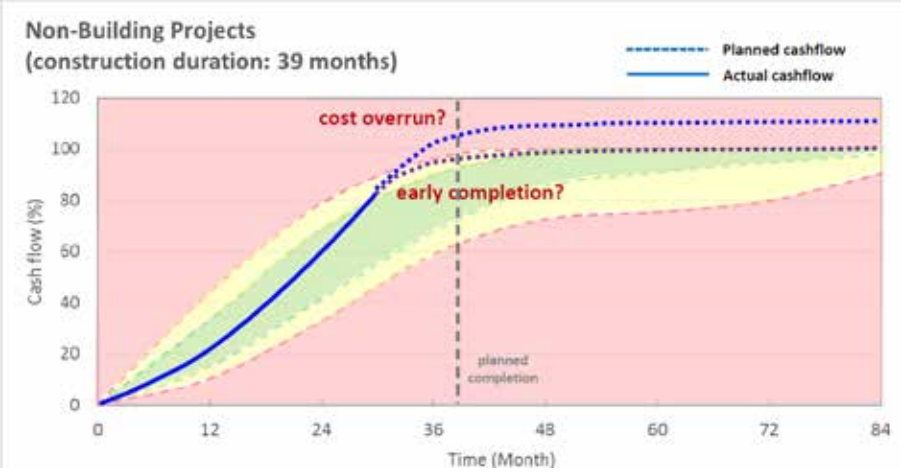
Third, red performance flags the strongest warning. When the project cashflow falls within the red zone, the Permanent Secretary for Development (Works) chairs a top management meeting, which monitors all projects in this category.

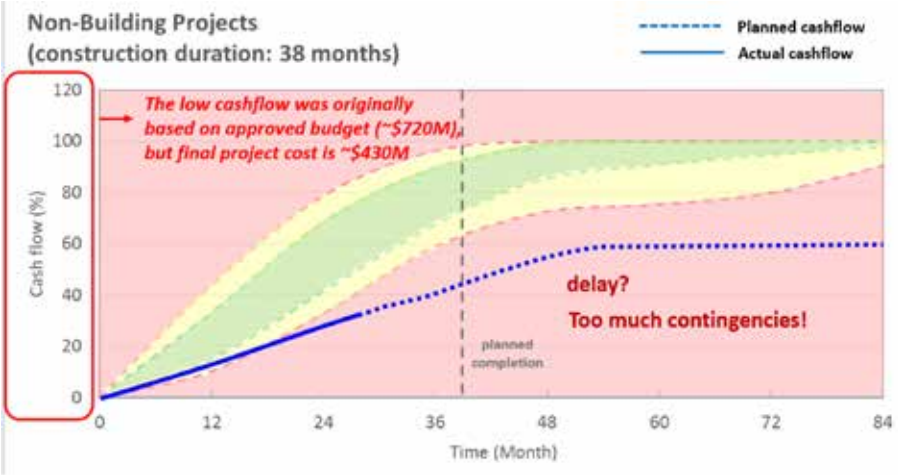


The monitoring system provides a better understanding of various elements of a project's performance. Here are some insightful examples from the first year of using the system.

The first project falls into the lower yellow zone, which indicates slow progress. The question to investigate is whether the project might be able to take actions to catch up (purple dotted line), or will be delayed (blue dotted line).

The second project falls into the upper yellow zone, which indicates fast progress or cost overrun. The team needs to investigate whether the project is indeed making very good progress and will be completed early (purple dotted line), or if the project will experience cost overrun (blue dotted line). In either case project plans and budgets might need to be adjusted as a result of the investigation.

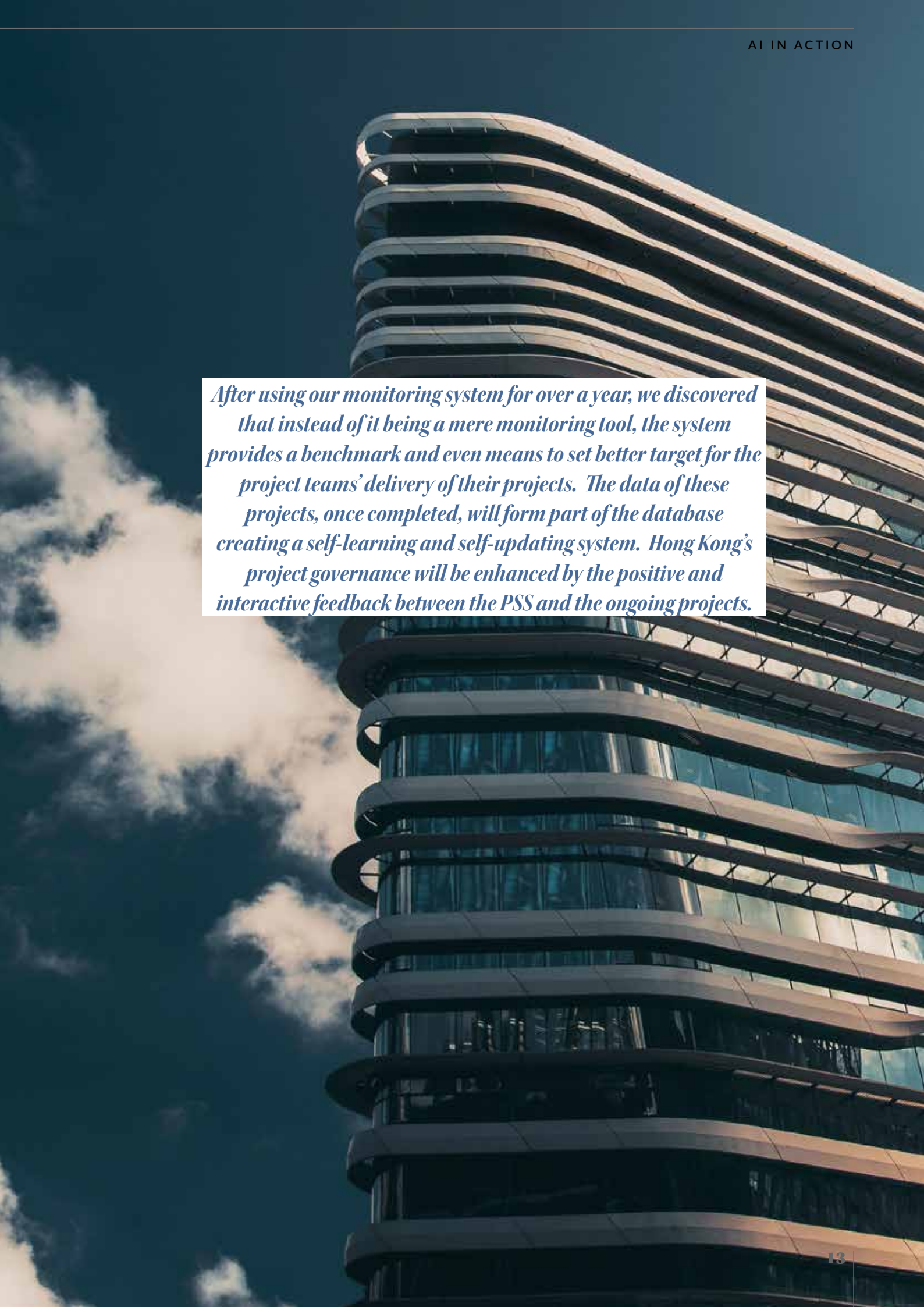




The third project falls into the lower red zone and has stayed persistently in this zone for more than a year.

This can signal a very long delay or an overinflated budget due to excessive contingency. In this case, the team investigated the project in-depth and found that the project carried too much contingency.

The project team reviewed the cost and developed a more realistic project budget. Once the cashflow was adjusted according to the new budget, the cashflow fell back into the normal zone.



After using our monitoring system for over a year, we discovered that instead of it being a mere monitoring tool, the system provides a benchmark and even means to set better target for the project teams' delivery of their projects. The data of these projects, once completed, will form part of the database creating a self-learning and self-updating system. Hong Kong's project governance will be enhanced by the positive and interactive feedback between the PSS and the ongoing projects.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THE DATA

AI ANALYSIS USED CASHFLOW DATA FROM 849 COMPLETED PROJECTS TO LEARN AND ANTICIPATE FUTURE PERFORMANCE

These closed projects have a total outturn cost of HKD 460bn (in 2019 HKD terms) and individual projects range from HKD 10m to 13bn. The mean project value is HKD 550m.

The project durations range from 10 months to 18 years, with an average 3-year duration. In total, the portfolio contains more than 2,700 years of construction activity.

The average project costs 15% less than forecast, and the range of cost outcomes is from 69% below the budget to 59% over budget. There's a far greater range in project duration, ranging from 41% shorter than planned to 317% longer than planned. The average delay is 34% for the delayed projects.

The historic 2008-17 dataset is representative of current performance, according to the Development Bureau's response to the Legislative Council for projects in 2018-19.

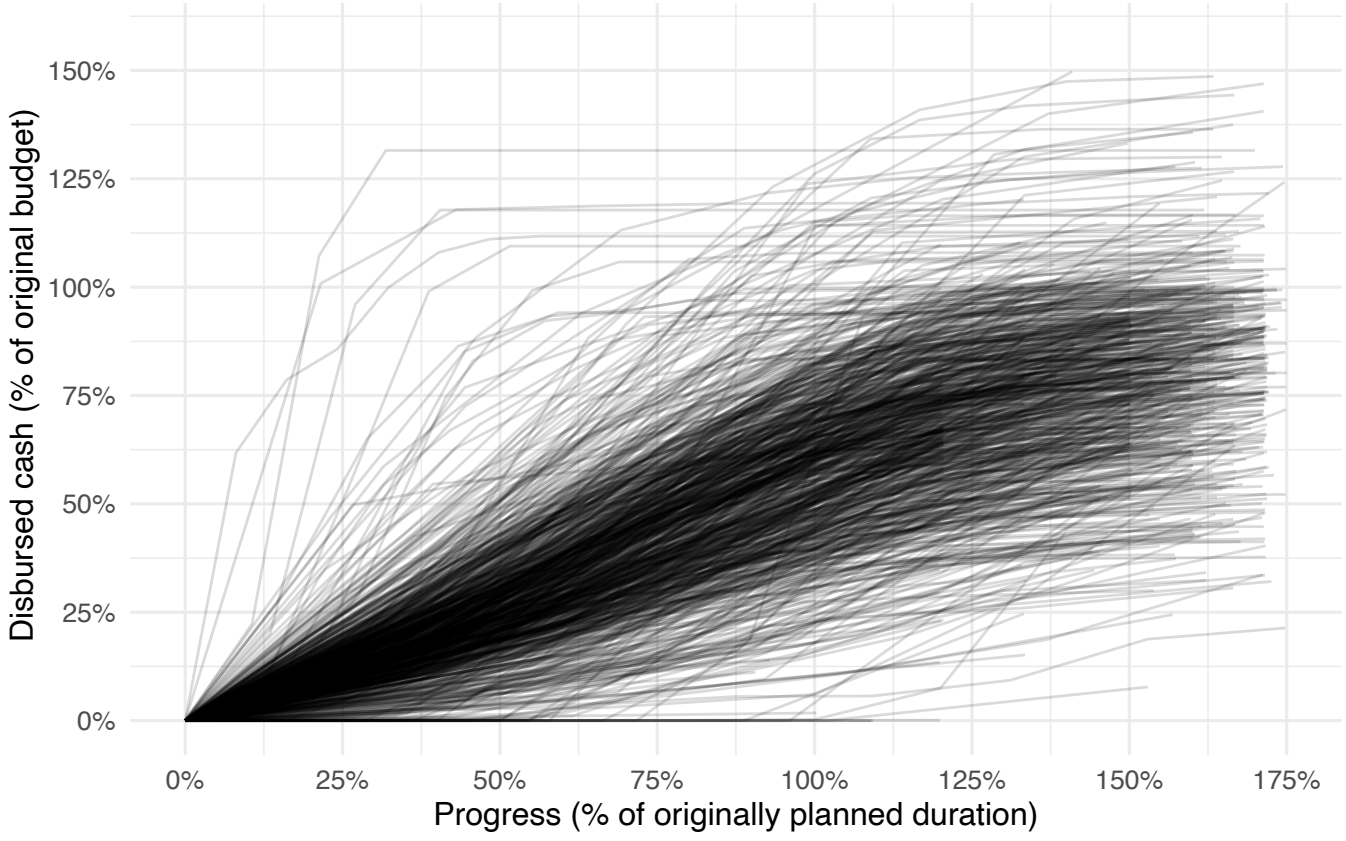
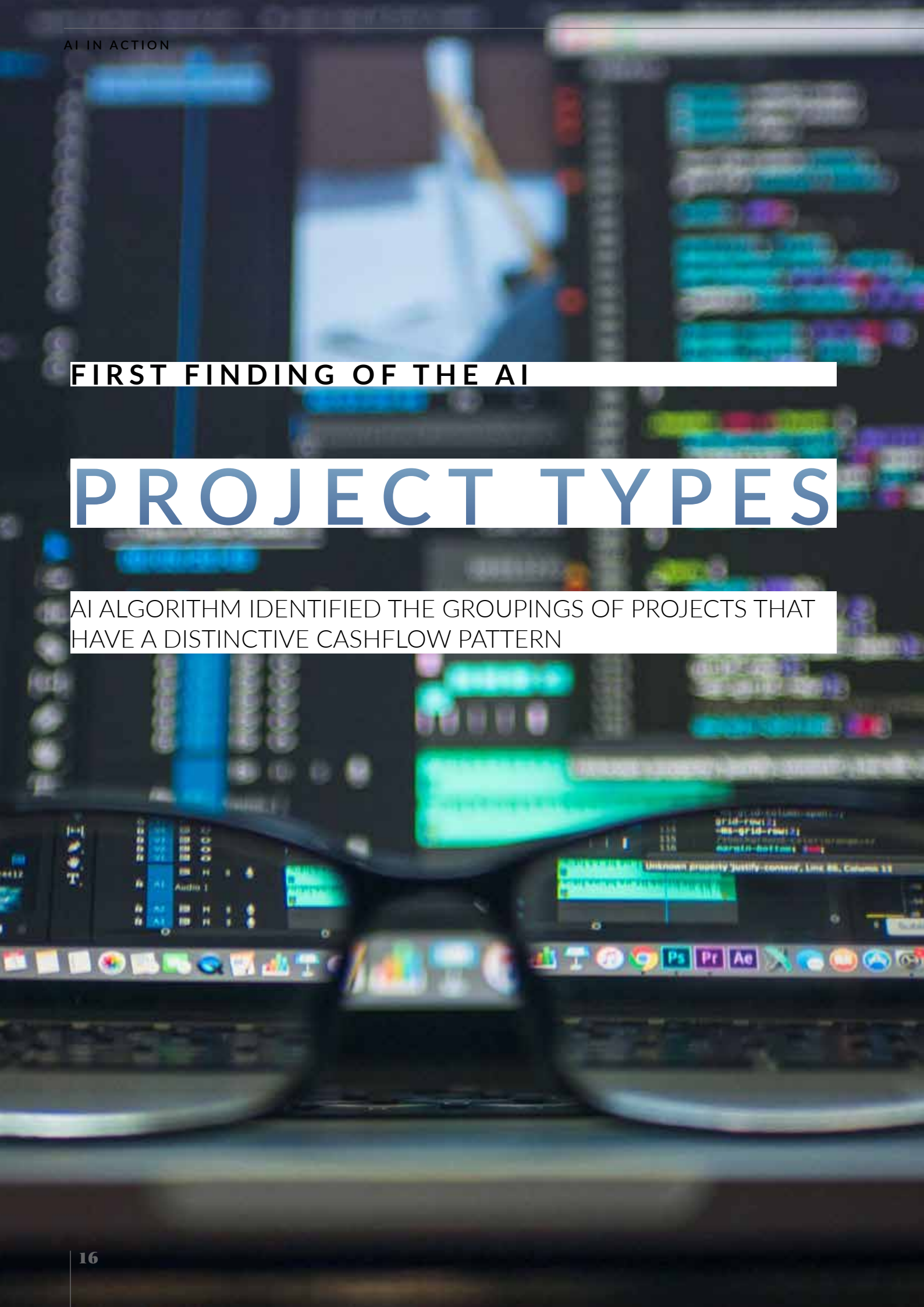


Figure 1: Cashflow curves of the 849 past, completed projects in the dataset



FIRST FINDING OF THE AI

PROJECT TYPES

AI ALGORITHM IDENTIFIED THE GROUPINGS OF PROJECTS THAT HAVE A DISTINCTIVE CASHFLOW PATTERN

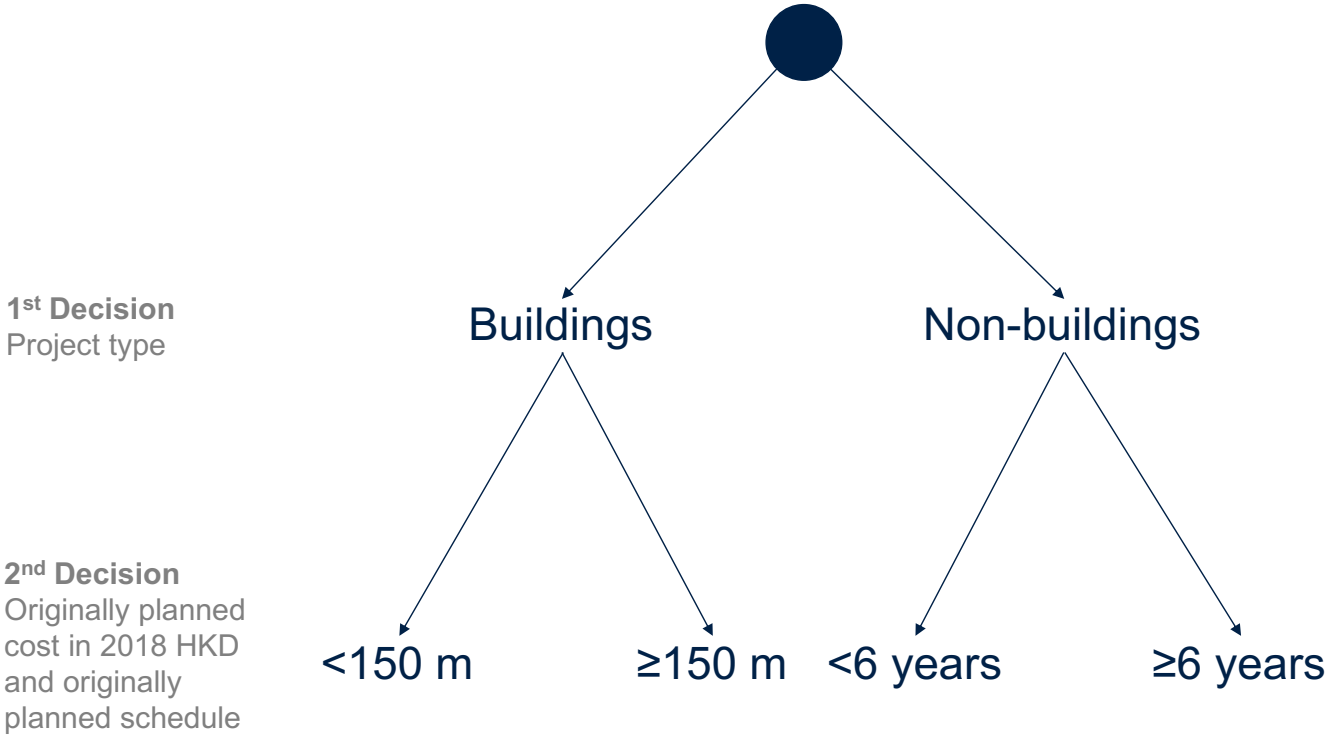


Figure 2: Decision tree to determine the S-curve grouping for projects

To analyse the cashflow data, two methods were selected: tracking annual performance as a percentage of the (1) outturn performance and (2) the original plan.

A relative timeline was determined for each project, with the percentage of the total duration assigned to each year. For instance, in a four-year project the first year would have 25% progress, the second 50% etc.

The data for the analysis comprised completed projects containing actual outcomes, but the forecasted outcomes will be used in the future, so the dual reporting will reflect cost and schedule performance as a percentage of the most recent forecast and the original plan.

The analysis used random forrests, an artificial intelligence method to analyse the data. This unsupervised learning algorithm considered all possible characteristics to group the projects then extracted the typical cashflows from the s-curves and compared the fit of the curves.

Analysis of the PSS identified that four types of projects had statistically significantly different outcomes. The analysis resulted in a decision tree, where the first decision divides all projects along the lines of building or non-building projects. Then the building projects are categorised by whether the original budget was smaller than HKD 150m or not and the non-building projects were categorised by whether the planned duration was less than six years or not.

RESULTS FROM THE AI

WARNING FLAGS

Each project was assigned a warning flag status; red, amber or green based on the outcome of the project. If the project finished in the middle 40% of the historic projects (30th–70th percentile) the project got a green flag. The bottom and top 5% of the project got a red flag (<5th or >95th percentile). All other projects got an amber warning flag (5th–30th and 70th–95th percentile).

After assigning the warning flag based on the project outcomes we trained three AI algorithms (gradient booster, neural network, rolling discretizer) to find out the warning flag status based on progress and cashflows.

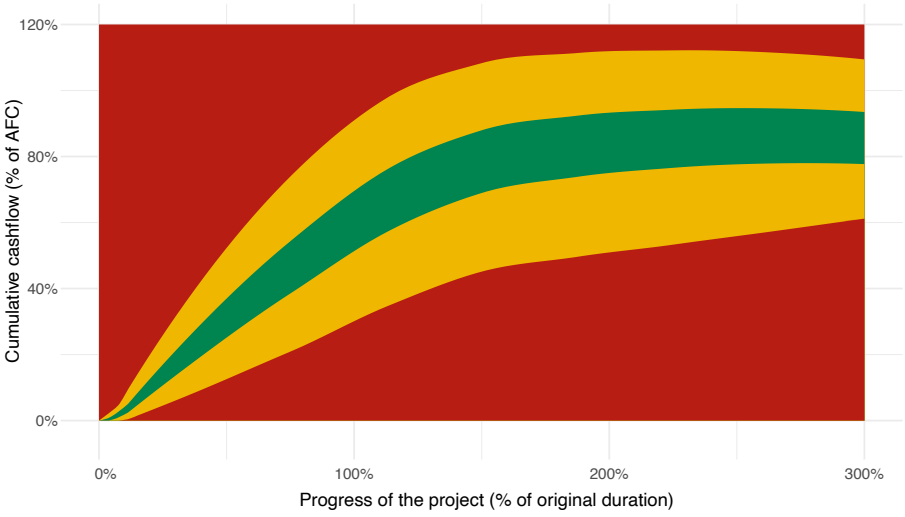


Figure 3: AI trained to assign red/amber/green traffic light for project cost performance

Figure 4: AI trained to assign red/amber/green traffic light for project schedule performance

The first AI assigns a warning flag for cost performance. The algorithm looks at progress and then the share of dispensed cash to date (fig. 3).

The second AI assigns a warning flag for schedule performance. The algorithm looks at the share of dispensed cash and then at the progress made (fig. 4).

The rolling discretizer, an algorithm specifically created for this

WARNING FLAG	AI: COST PERFORMANCE	AI: SCHEDULE PERFORMANCE	S-CURVE BY PROJECT TYPE	RANDOM ASSIGNMENT
RED OVERRUN	69%	63%	40%	3%
AMBER OVERRUN	56%	18%	40%	16%
GREEN	65%	53%	38%	25%
AMBER UNDERRUN	53%	18%	37%	16%
RED UNDERRUN	66%	32%	8%	3%

Table 1: Accuracy of predictions by the best AI algorithm compared with predictions only based on typical S-cuves by project types and random assignment of warning flags. Accuracy is measured as the percentage of agreement between the assigned warning flag while the project is delivered and the equivalent warning flag at project completion.

task, achieved the most accurate predictions in unseen test data. To validate the predictive power of the algorithm the data were split into a training and a test set. The AI learned from 70% of the data how to assign warning flags. Then the accuracy of the warning flags was measured on the remaining 30% of the data, which the algorithm had not seen before.

The AI achieves an excellent performance, especially in identifying the red projects correctly. The performance is well balanced across the different flags.

53%–69% of all the flags assigned to the observations are accurate. This means, for example, that if the AI assigns a red flag for a cost overrun the algorithm is accurate nearly 7 out of 10 times.

The accuracy of the schedule flags is slightly worse. Here the AI is accurate in its prediction 18%–63% of the time.

The AI outperforms the split by project type, which was only accurate in 8%–40% of predictions.

The AI vastly outperforms randomness. If we simply made an uninformed "lucky" guess about the project's risk we would get it right in 3%–25% of times.

Especially for the very high risk category "red" the AI is more than 20–times better than a lucky guess.

In addition to the validation with a test and training set of the data, we tested how little data the AI needs to achieve this level of accuracy. The analysis shows that is possible with as little as 10% of the data. We were surprised by this finding, because we always assumed that AI needs lots of data. It turns out we were wrong. Any organisation wishing to integrate AI into their early-warning-sign system needs some but not vast amounts of data.

The AI is far from perfect; the accuracy is surpsingly good even though the algorithm only knew the cashflow and type of a project.

Adding more data in the future will certainly improve the accuracy.

LOOKING FORWARD
WITH THE AI

PREDICTING COST

The accuracy of the warning flag AI is promising enough to train more algorithms on an even more detailed task: forecast the outturn cost of projects. A more complex AI, a deep artificial neural network, predicted the final outturn cost with an average error of only ±8%. The accuracy is as good as a Class 1 estimate.

The next challenge we set for the AI algorithms was to predict the final outturn cost of projects.

The AI only knew the percentage of progress the project had achieved so far, measured against the planned project duration at final investment decision and the cashflow spent to date as percentage of the budget, that was approved at the final investment decision.

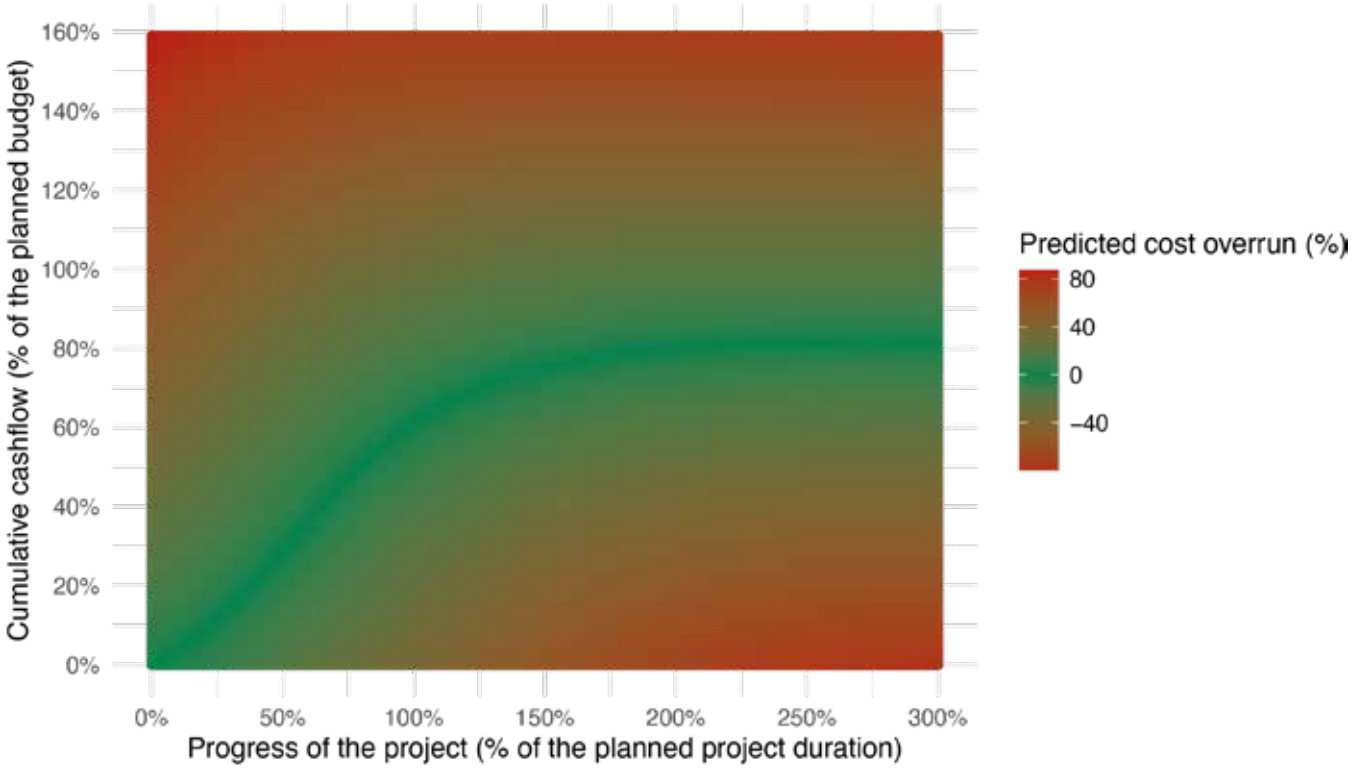
For this challenge we tested many different AI and non-AI algorithms, including linear regressions, support vector machines, gradient boosters, random forrest regressions, k-nearest neighbours, multilayer percepetrons, simple deep neural networks and complex deep neural networks.

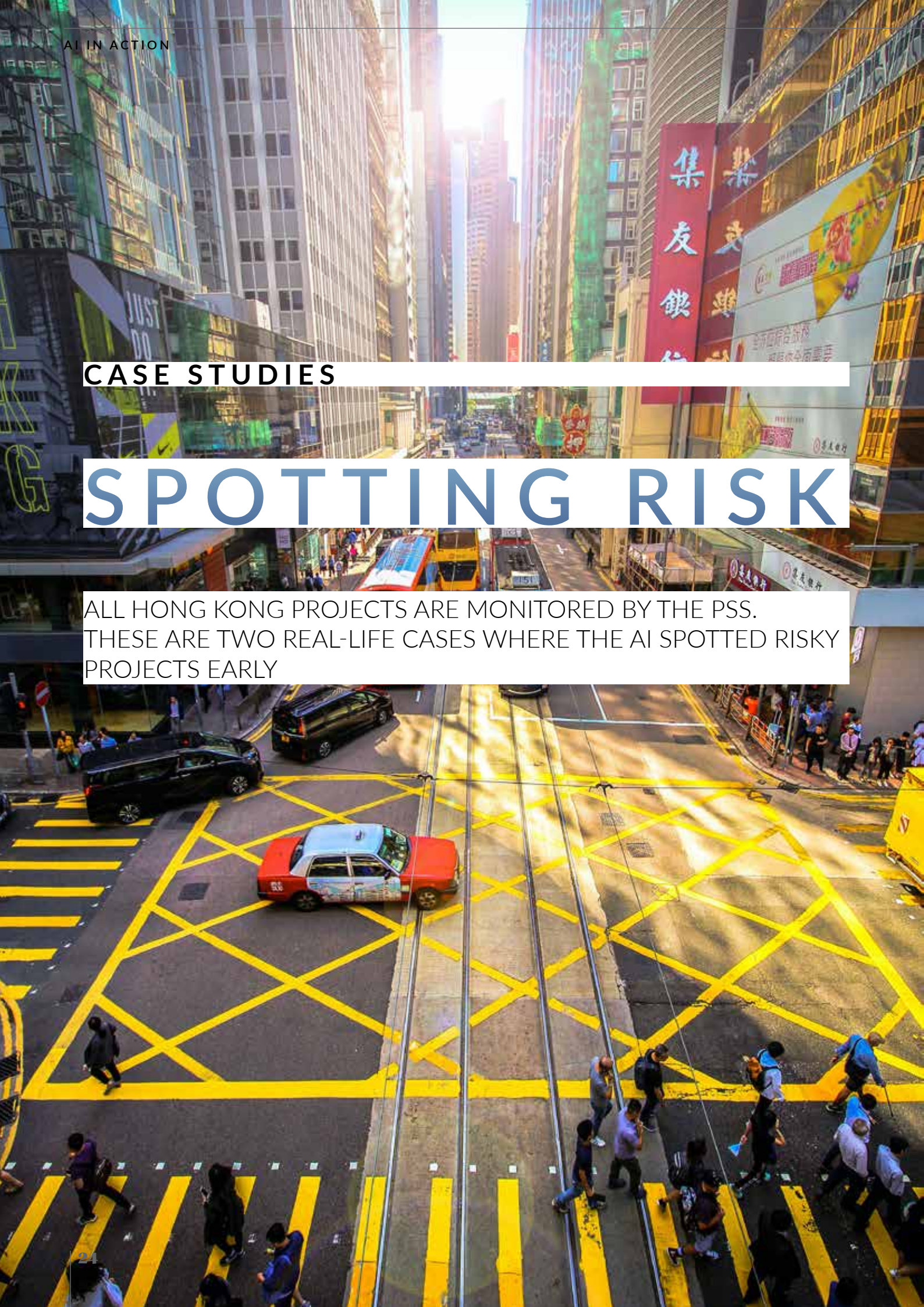
We measured the error of the predicted outturn cost in the training data, which tells us how good the AI is at summarising the data it knows. We then gave the AI unseen data to test the prediction. As before, the AI used 70% of the data to train and 30% for testing.

The best performing algorithm was the simple deep neural network. The mean squared error of the predictions for the test data was 1.6 percentage points. The mean absolute error in the test data was 7.9 percentage points.

This means that on average the forecasted outturn cost was within ±8% at the portfolio level. The mean squared error, which is similar to the standard deviation, is only ±1.6%, thus 68% of predictions are within a range of ±1.6%, 95% of predictions are within a range of ±3.2% and 99.7% of predictions are within ±4.8% of the predicted cost. The mean absolute error of the prediction is ±7.9%, therefore an indication of the skew in the data, where very large overruns and fat tails are not uncommon.

The AI estimate is in line with what conventional cost estimation practice considers to be the best cost estimate achievable. The Association for the Advancement of Cost Engineering (AACE) suggests that international best practice for a best-in-class cost estimate has an error between ±3% and ±15%; to achieve an estimate with this narrow error range, 100% of design needs to be completed and detailed information of unit cost and prices needs to be available. The estimate of the AI falls within the range expected for a Class 1 cost estimate.





CASE STUDIES

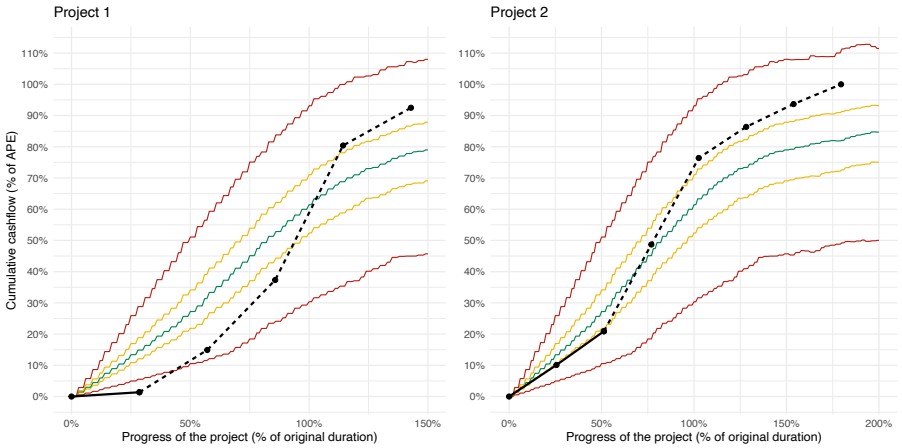
SPOTTING RISK

ALL HONG KONG PROJECTS ARE MONITORED BY THE PSS. THESE ARE TWO REAL-LIFE CASES WHERE THE AI SPOTTED RISKY PROJECTS EARLY

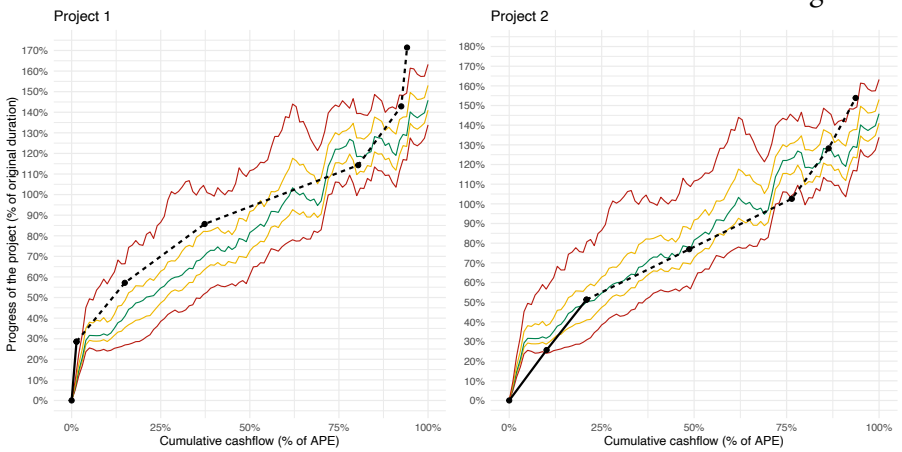
We selected two capital works projects from the portfolio to run the AI analyses. Project 1 has an approved project cost estimate (APE) of HKD 5.2bn with completion within 3.5 years. Project 2 has an approved budget of HKD 1.3bn with a construction duration of 3.9 years. Project 1 has completed its first year of construction. Project 2 has completed its first two years of construction.

The latest cashflow information shows that project 1 has spent 1% of its cash and is nearly 29% complete when measured against the originally planned duration. Project 2 is 51% complete and has spent 21% of its cash.

First, the AI assigned warning flags. Project 1 has a red flag. Project 1 has been spending the budget slower than the AI anticipates based on the typical spending pattern of capital works projects in Hong Kong. The project's own forecast of spend (dotted line) shows that this trend will reverse in the next two years and exceed usual patterns in years 4 and 5. The AI's flag raises questions about this unusual profile of acceleration and suggests further investigation.

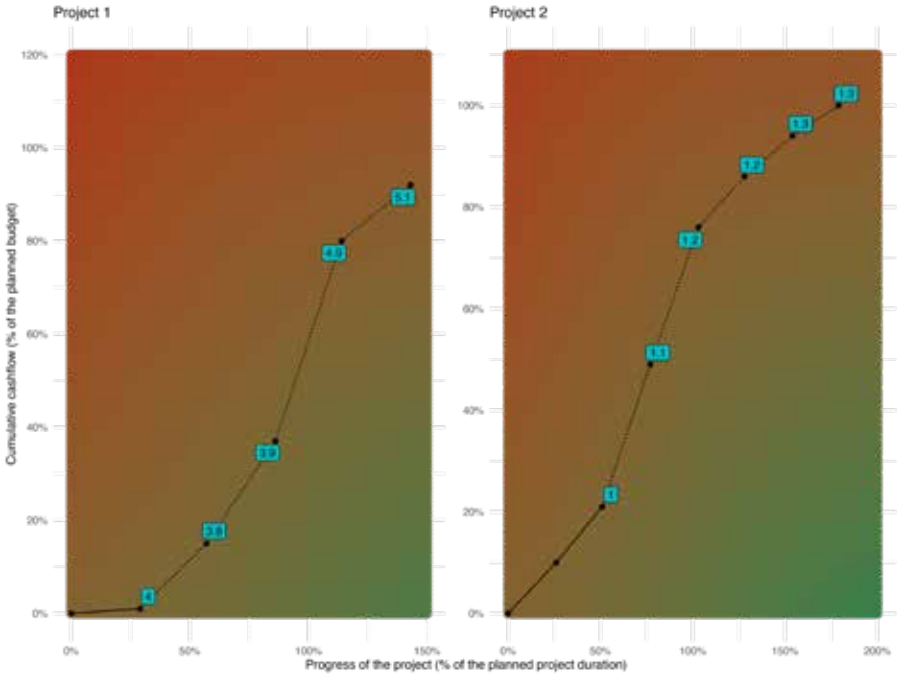


Project 2 receives a yellow flag. The project is spending its budget more slowly than typical projects but it forecasts that it will soon be in line with others. The schedule flags show a similar pattern. Project 1 gets a red flag for being very late if it can keep up the expenditure as is (under the assumption that this is not indicating a big cost underrun).

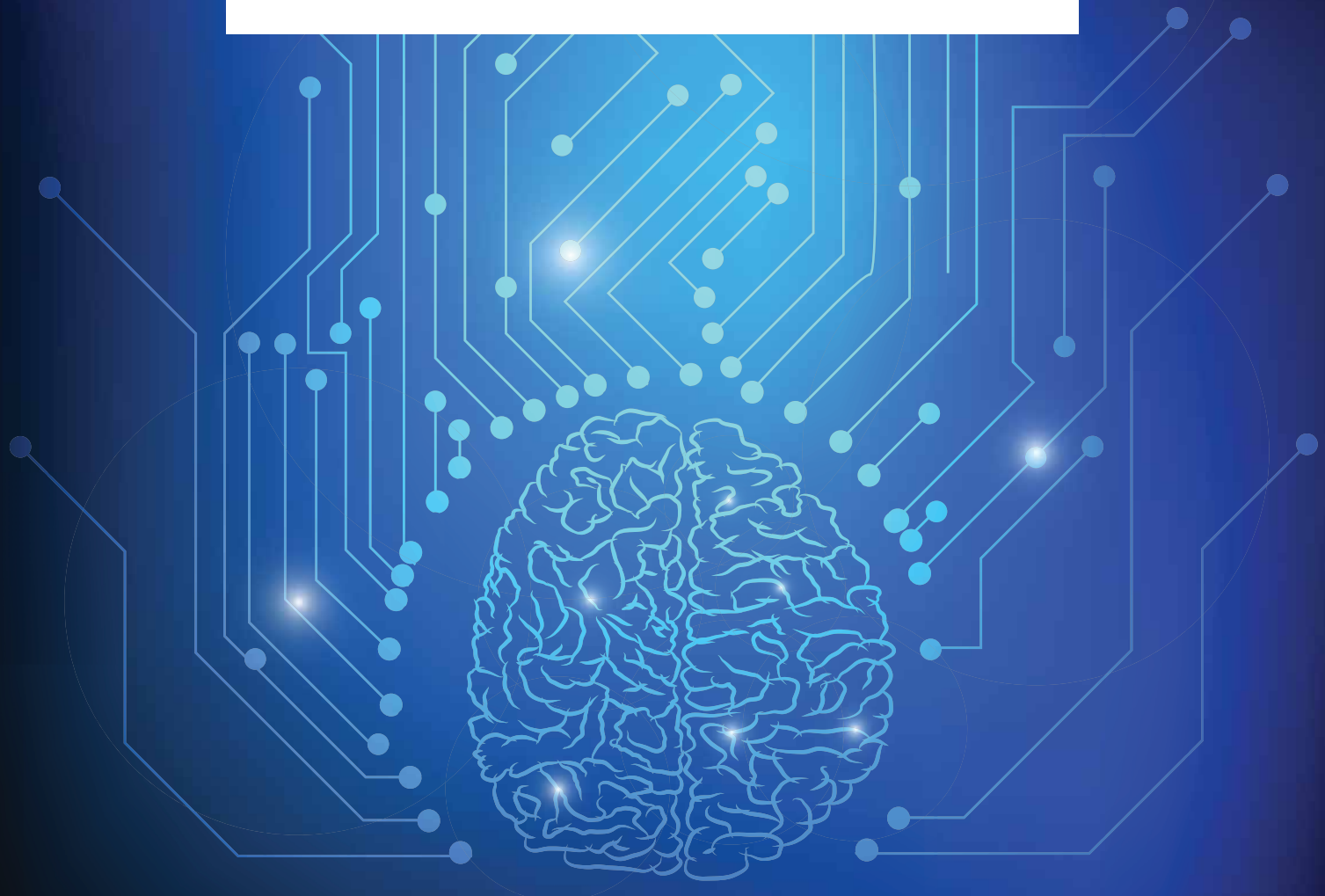


Project 2 is progressing like a typical project in Hong Kong and the AI assigned a green schedule flag. But the AI raises questions about the plans after year 5.

The AI also produces a cost forecast of the final outturn cost. At the moment Project 1 is forecasted to cost HKD 4.0bn. For this estimate, the AI assumes that the project will not follow its own forecasted trajectory but behave more like a typical project in the future. However, the unusual pattern of expenditure means that if the project does indeed accelerate its spend the cost are likely HKD 5.1bn close to the APE. Project 2 has similar issues. The AI forecasts outturn cost of HKD 1.0bn. The project's own forecasts show a spike in spending near the end; if that holds true the AI forecasts spending of HKD 1.3bn. Again the readiness for acceleration should be investigated.



The enhancement of the PSS does not stop here. Our future plans include adding more detailed project data, further developing the AI to enhance the predictive power and extending the PSS to railway projects in collaboration with other international regions. Our innovations will not only support Hong Kong's ambitious vision but also benefit projects worldwide.



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Development Bureau

Hong Kong's land mass, mountainous terrain, Victoria Harbour and surrounding water body are precious assets of our city. Making the best use of these limited resources to meet the wide-ranging needs of our community, amid fast-changing global competition and regional development, is a huge challenge.

We need to provide homes, work space and service space for our 7.5 million, and still growing, population, while maintaining Hong Kong's leading edge as a financial and business centre both globally and within the region. A t the same time we must treasure our natural and built heritage, home to diverse species and a space for public enjoyment. The growth of our city must be able to effectively respond to the needs of our community, in line with the principle of sustainable development.

The Development Bureau is the policy bureau responsible for championing this agenda for our city's development. Our work consists broadly of two main areas: planning, land and building development; and infrastructure development.

CEMP
CENTRE OF EXCELLENCE FOR MAJOR PROJECT LEADERS

The Centre of Excellence for Major Project Leaders (CoE), under the Development Bureau, was established in July 2019. As the first of its kind in Asia, the CoE offers a high-level project management and leadership development programme to senior government officials and construction leaders to equip them with a more innovative mentality and world-class leadership skills to uplift their project delivery capability and improve project performance as a whole.

The CoE is a key expert knowledge hub for providing vital support in the project delivery. Drawing together the experts and practitioners, the CoE strives to promote best practices and contemporary approaches in delivering public projects. It organises forums, seminar, conferences, visits, etc. to gather expert knowledge, deliberate solutions for tackling challenges and develop skills and knowhow for uplifting project performance, as well as fostering a culture of innovation, professionalism and excellence in project delivery.

PROJECT STRATEGY AND GOVERNANCE OFFICE

The Government's annual expenditure for projects was on average HKD 80bn over the past three years and is expected to see constant growth in coming years. The annual construction output of the public and private sectors will be up to HKD 325bn by 2031. In addition to this workload, we are facing the challenges of high construction cost and an ageing construction workforce. Moreover, the general public increasingly expects better performance of public works projects.

In June 2016, the Project Cost Management Office was established under the Development Bureau to support the delivery of projects in a timely and cost-effective manner. In April 2019, the office was upgraded and renamed as the Project Strategy and Governance Office for implementing strategies and reinforcing capabilities in cost and project governance.

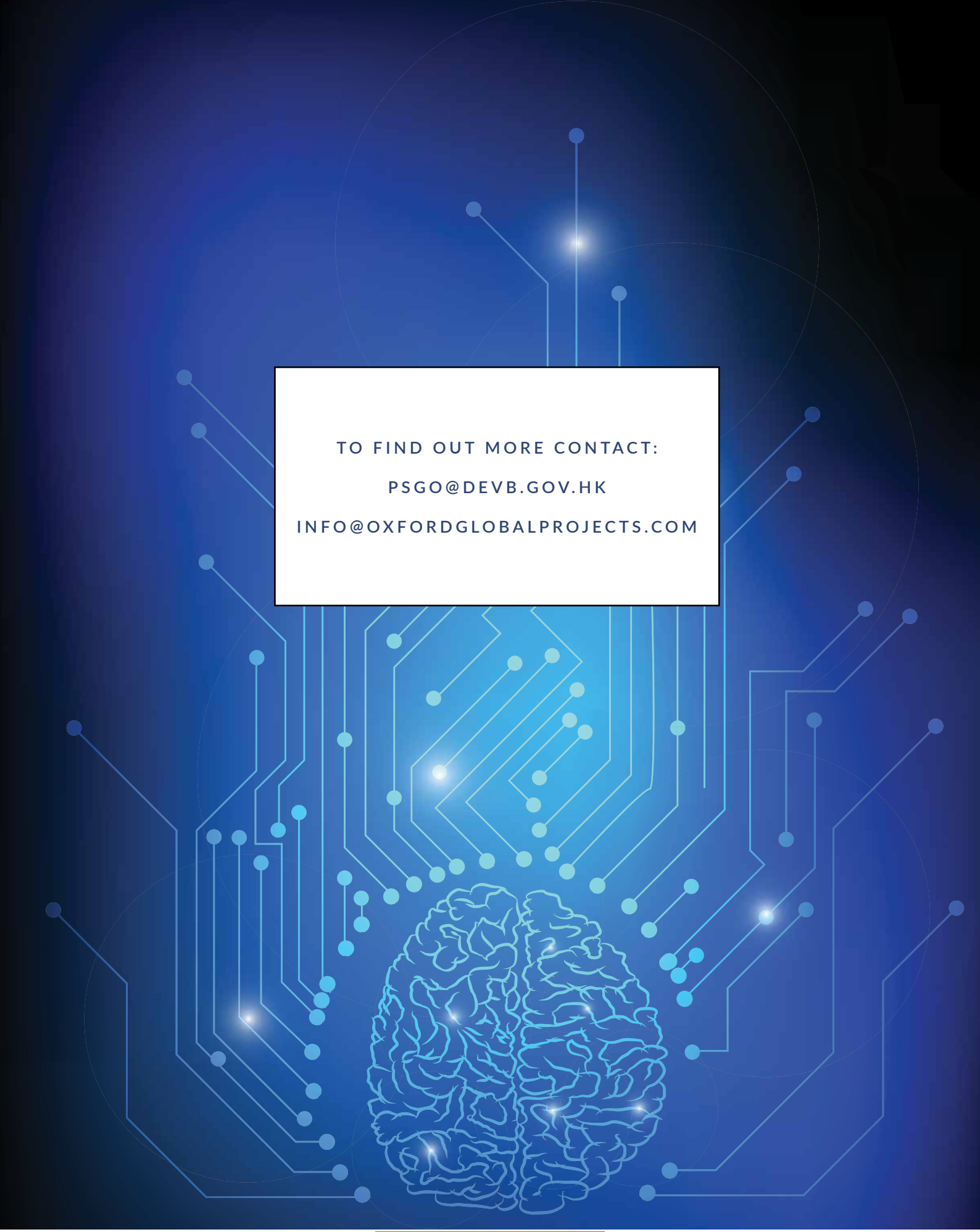
PSGO adopts a holistic approach to strengthening cost management and improving the performance of public works projects.

OXFORD | GLOBAL PROJECTS

Oxford Global Projects helps organizations to successfully deliver major projects. We advise projects based on award-winning research. Our founders are the most-cited scholars on major projects worldwide.

We have the largest high-quality datasets on project performance in the world. Our data cover more than 16,000 projects worth 3 trillion USD across key sectors. We turn that data into research-based approaches that de-risk projects, programs, and portfolios.

We partner with clients on creating the most accurate forecasts, setting up projects for success, establishing early-warning-sign systems, turning projects around, and training project leaders. We work with clients in all sectors to deliver critical projects, programs and portfolios.



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