Report of	Thomas Wood
Specialist field	Machine learning and artificial intelligence
On behalf of	Bridge Trust Investment Ltd

Expert witness report

Bridge Trust Investment Ltd v Wind Path Ltd
Title of the action

2021 50186
Court reference number

Final report of Thomas Wood for High Court of Justice Queen's Bench Division (Technology and Construction Court)

Dated	8 September 2021
Specialist field	Machine learning
On behalf of the Claimant/Defendant (or both if single joint expert):	Bridge Trust Investment Ltd
On the instructions of:	Clarkson Jones Solicitors LLP
Subject matter:	The disputed investment of the Claimant in Wind Path Ltd (Defendant). Expert opinion regarding allegations of misrepresentation of the Defendant's technology at time of due diligence.
Signed	[REDACTED]

Thomas Wood
8 September 2021

Thomas Wood
[REDACTED]
fastdatascience.com
Ref. EW-02

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Report

1 Introduction

1.01 The writer

1. My name is Thomas Wood and my specialist field is machine learning and artificial intelligence.

2. Full details of my qualifications and experience entitling me to give expert opinion evidence are in Appendix 1.

1.02 Summary background of the case

1. The case concerns a dispute over an investment that Bridge Trust Investment Ltd (the Claimant) made in Wind Path Ltd (the Defendant) in 2020.
2. The Claimant alleges that the Defendant's technology was misrepresented. There is a chronology of the key events in Appendix 7. I have been instructed to ascertain whether incorrect information was provided to the Claimant company at the time of due diligence.

1.03 Summary of my conclusions

1. This report will show that, in my professional opinion, the **accuracy** of the Defendant's technology was misrepresented by the Defendant at the time of the Claimant's due diligence exercise, and that the Defendant failed to disclose during the due diligence that the **test dataset** of images used to evaluate the model had also been used as a **training dataset**.
2. However the Defendant did not misrepresent the amount of manual intervention involved to run the model.
3. In my professional opinion, the undisclosed information regarding the model **accuracy** would have had a significant impact on the valuation of the Defendant company in 2019.

1.04 Technical terms and explanations

1. I have indicated any technical terms in **bold type**. I have defined these terms when first used and included them in a glossary in Appendix 8. I have also included in Appendix 5 extracts of published works I refer to in my report.

1.05 Disclosure of interests

1. I have no personal or professional connection with the parties, witnesses or advisers, or actual or potential interests that might adversely or potentially affect my independence.

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2 The issues to be addressed and a statement of instructions

This report has been prepared on the instructions of Clarkson Jones Solicitors LLP, in a letter of instruction dated 19 July 2021.

2.01 The purpose of the report

I have been asked to prepare this report concerning the question as to whether the Defendant's technology was misrepresented prior to the investment.

2.02 Instructions

I have been instructed to examine the Defendant's computer programming code, interview relevant persons at the Defendant company, and prepare a full and detailed report to clarify if any misrepresentation took place during the due diligence.

2.03 Documents provided

1. Original due diligence report dated 10 December 2019
2. Emails between the claimant and defendant company from 2019 to 2020.
3. PowerPoint presentation by Defendant dated 2 October 2019
4. PowerPoint presentation by Defendant dated 16 August 2019
5. White paper published by Defendant on their website, timestamped 2 February 2019

2.04 The issues to be addressed

The issues are as listed below:

Issue 1. Were the **accuracy** figures provided by the Defendant in 2019 incorrect and misleading?

Issue 2. Did the Defendant hide the fact that considerable manual work is required to run their machine learning model, i.e. the process is not fully automated?

Issue 3. If information was concealed during the due diligence, what was the effect on the value of the company?

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3 My investigation of the facts

3.01 Assumed facts

1. The Defendant, a company of four employees, develops a machine learning technology for automation of inspection of wind power turbines, enabling wind farm operators to save money that would otherwise be spent on manual work.
2. The Claimant invested a total of £9.5 million in the Defendant in 2020, with the aim of expanding into European and Asian markets. The technology is claimed to be able to identify common defects in drone images of turbines, from gouges to scratches.
3. The Claimant based their investment decision 75% on the technology in the Defendant and 25% on the makeup of the employees.
4. A due diligence exercise was conducted by Dr. Noah Sullivan working for the Claimant on 2-6 November 2019. The report is attached.
5. The due diligence report states figures for the **accuracy** of the model in identifying turbine defects. The due diligence report also states that the system was able to inspect a wind farm image fully automatically, and achieved an **accuracy** of 98.5% in identifying defects when evaluated on a **test dataset** of 200 images.
6. Following acquisition of the company, the Claimant asserts that the technology failed basic checks in the pre-sales process when being demonstrated to new clients. The system was unable to deliver any image analyses any faster than a human team, and required considerable correction.
7. The Claimant states that they have been unable to proceed through the sales process with any clients in the wind industry, with potential clients citing the four hours of human intervention needed per turbine as being unacceptable, and have consequently made a considerable loss on the investment.
8. The Claimant asserts that the Defendant had trained the machine learning model on the same images (**training dataset**) used for validating the model (**validation dataset**) in the due diligence process, but did not disclose this to the Claimant.

3.02 Enquiries/investigation into facts by the expert

1. I obtained access to the **code repository**, **training, validation and test datasets** and file systems of the defendant. I also viewed the emails sent by Dr. Morgan Parry, CTO at the company, during the due diligence process, and I have attempted to reproduce the code run during the due diligence. I attended the premises of the Defendant and the Claimant and interviewed all employees of the Defendant.

2. The **code repository** (Github repository) allowed me to see the entire program and model of the Defendant's system in a snapshot of its state from November 2019, the date of the due diligence exercise.

3.03 Documents

1. Appendix 4 contains the original due diligence report.
2. I have also examined two PowerPoint presentations and one white paper which were shared by the Defendant with both the Claimant and Dr. Sullivan in the period from August to November 2019.

3.04 Interview and examination

1. On 1 July 2021 I visited the Defendant in person and interviewed Dr. Parry and the technical team. I asked for access to all code and emails regarding the due diligence process.
2. Dr. Parry explained that Dr. Sullivan visited the premises and was shown the model in action. Dr. Sullivan had documented that he personally tested the model on the 200 images of test data and the model achieved 98.5% **accuracy** on the **test dataset** of images. When I asked Dr. Parry if the 200 images used to test the model had also been used as the **training dataset**, he was unable to recall.
3. The due diligence report also stated that the model required no human intervention. When I asked Dr. Parry about this, he also confirmed that the demonstration run during due diligence was entirely computer-driven and had no human decision-making steps.
4. When I spoke privately to two of the technical employees, AB and KG, they distinctly recalled being asked to manually annotate images prior to the due diligence exercise, however they did not recall any manual annotation during a live demonstration of the technology.

3.05 Research

1. Using the **code repository** on the Defendant's premises, I have attempted to reproduce the steps to train the machine learning model and evaluate it using the code in its state as of November 2019.
2. I also took a selection of open source image recognition libraries (**OpenCV, Keras, TensorFlow**) and tested them on the same image recognition problem.

3.06 Measurements, tests and experiments etc

1. In the **repository** snapshot, the dataset consisted of 2000 images at that date, which were drone photographs of wind turbines collected by staff at the Defendant.
2. The images are categorised into two folders, Set A (containing 1800 images) and Set B (containing 200 images).

3. Crucially, the 200 images in Set B that were used to generate the 98.5% **accuracy** figure were also used for model development. When I trained a new model using the 1800 images (Set A) that were not used for model testing, the **accuracy** figure dropped to 90%. However only by including all test images in the training data (Set A + Set B) was I able to reproduce the 98.5% figure.

4. This evidence strongly points towards the model being trained on both Set A and Set B, despite being evaluated on Set B.

Training dataset	Test dataset	Accuracy resulting
Set A (1800 images)	Set B (200 images)	90%
Set A+Set B (2000 images)	Set B (200 images)	98.5%

5. Full details of my experimental results are given in Appendix 9.

6. The three open-source libraries (which are free to use with no commercial restrictions) gave **accuracy** figures ranging between 86% and 92% on the same image recognition problem, meaning that in November 2019 there was no significant difference between the performance of the Defendant's technology and the simplest free and off-the-shelf product.

7. In the month of October 2019, there were a total of 40 **commits** (timestamped modification of the program) to the **repository**. On 1 November 2019 alone, the day before the due diligence was due to begin, more than 80 **commits** were made. Two of these **commits** allowed the output of the model to be sent to another point, such as a screen, where a human would be able to manually alter the output. This change was **reverted** on the same date after two hours.

3.07 Facts obtained by others

N/A

4 My opinion

1. In my opinion, one key aspect of the state of the technology was not disclosed during due diligence, namely the **accuracy** of the machine model. However, the amount of human intervention required by the system was correctly represented at due diligence. The accuracy of the model and the low amount of human intervention required were the main selling points of the technology and appear prominently in all promotional presentations shared by the Defendant in 2019.

2. **Issue 1. Were the accuracy figures provided by the Defendant in 2019 incorrect and misleading?**

3. The **accuracy** figures provided during the due diligence were indeed misleading. The machine learning model demonstrated to and given to Dr. Sullivan during the due diligence had been developed and trained on a small **training dataset** of images which included the entire **test dataset**.

4. It is a "golden rule" of machine learning and artificial intelligence, that all machine learning models must be evaluated on an unseen **test dataset**, and it is inconceivable that the entire technical team at the Defendant, many of whom have postgraduate degrees in the field, would be unaware of this.

5. The opening chapter of one of my textbooks in machine learning (Appendix 5) makes the following statement:

6. *...we should not use [the **test dataset**] for model fitting or model selection, otherwise we will get an unrealistically optimistic estimate of performance of our method. This is one of the "golden rules" of machine learning research.*

7. On balance, I find it implausible that a team with postgraduate degrees in machine learning would have broken this "golden rule" unknowingly.

8. **Issue 2. Did the Defendant hide the fact that considerable manual work is required to run their machine learning model?**

9. I found that the **code repository** showed frequent changes prior to the date of due diligence, where it appears that the code was being made to look more acceptable for the due diligence investigation.

10. The footprint of **commits** to the **code repository** in the days preceding and following the due diligence exercise indicates that at a point immediately prior to the due diligence, there was a modification in the code where data could have been sent to human annotators rather than proceeding through the automated system. However this **commit** was **reverted** immediately prior to the due diligence.

11. I have found no evidence pointing towards any kind of misrepresentation of the amount of manual work involved in running the model having taken place during the due diligence.

12. On balance, the four hours of human intervention per turbine cited by the Claimant are likely to be due to other factors, such as a failure of the machine learning model to generalise to wind turbine images in different locations, lighting conditions, climates, or of different makes and models than the images in the **training dataset**. Although not ideal, this does not point towards any kind of foul play or cover-up in the due diligence process.

13. **Issue 3. If information was concealed during the due diligence, what was the effect on the value of the company?**

14. When I reconstructed the **code repository** from November 2019, I have found that the technology's performance on the wind turbine image classification task is not significantly better than using the simplest off-the-shelf open source libraries. For this reason, the technology as of 2019 was no more capable than a free open-source alternative for this task.

15. Given that the Claimant's investment decision was based on a combination of the Defendant's employees and the Defendant's technology, in my professional opinion, this would have a significant impact on the value of the Defendant company.

16. I would advise to consult the Claimant's in-house financial due diligence team to establish a quantum for the overvaluation.

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Statements and declarations (civil proceedings)

5 Statement of compliance

I understand my duty as an expert witness is to the court. I have complied with that duty and will continue to comply with it. This report includes all matters relevant to the issues on which my expert evidence is given. I have given details in this report of any matters which might affect the validity of this report. I have addressed this report to the court. I further understand that my duty to the court overrides any obligation to the party from whom I received instructions.

6 Declaration of awareness

I confirm that I am aware of the requirements of Part 35 and Practice Direction 35, and the Guidance for the Instruction of Experts in Civil Claims 2014.

7 Statement of truth

I confirm that I have made clear which facts and matters referred to in this report are within my own knowledge and which are not. Those that are within my own knowledge I confirm to be true. The opinions I have expressed represent my true and complete professional opinions on the matters to which they refer.

I understand that proceedings for contempt of court may be brought against anyone who makes, or causes to be made, a false statement in a document verified by a statement of truth without an honest belief in its truth.

8 Statement of conflicts

I confirm that I have no conflict of interest of any kind, other than any which I have already set out in this report. I do not consider that any interest which I have disclosed affects my suitability to give expert evidence on any issue on which I have given evidence and I will advise the party by whom I am instructed if, between the date of this report and the trial, there is any change in circumstances which affects this statement.

Thomas Wood 8 September 2021

[REDACTED]

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Appendices

1 My experience and qualifications

1. I am the director of data science consulting company Fast Data Science Ltd, incorporated in 2018.
2. I have been working in machine learning, artificial intelligence and data science since completing a Masters in the field (MPhil Computer Speech, Text and Internet Technology) at the University of Cambridge in 2008.
3. I have worked on machine learning technology for a number of well known organisations such as Tesco and the National Health Service. I regularly conduct due diligence exercises for private equity investors who are considering investment in companies in the machine learning space.

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2 Curriculum Vitae

Professional profile

Data scientist available for contracts and consulting work.
Experience in running machine learning projects with complex requirements and international teams of developers, from data gathering to deployment.
Specialising in two major areas of AI: Computer Vision and Natural Language Processing.
NLP: spoken and written dialogue systems, information retrieval, document classification.
Deep learning, image processing, convolutional neural networks for both images and text.
International experience: several years in Spain and Germany and fluent command of several European languages.

Technologies

Python, Java, C++
Machine learning/neural networks: TensorFlow, Scikit-Learn, Spark MLlib, Docker, Scipy, Numpy.
Experience training models on GPUs and GPU clusters.
Experience developing for: Windows, Mac, Unix, Android.
NLP: OpenNLP, NLTK, Stanford NLP, Weka.

Career summary

Data Scientist (freelance consultant) – London, UK — Apr 2019-present
Consultancy in data science and machine learning via company Fast Data Science Ltd, including due diligence work.

Data Scientist (contractor) – Boehringer Ingelheim, Ingelheim am Rhein, Germany/London — Apr 2019-Mar 2020

- Major European pharmaceutical company.
- Developed predictive model in TensorFlow using GPU for clinical trial protocols.
- Processing of highly domain specific texts.

Data Scientist (contractor) – Tesco plc, London, UK — Apr 2018-Mar 2019

- Designed, developed, trained and deployed two large scale machine learning solutions.
- Vehicle route planning for 4000 stores around the UK.
- Order prediction for 15 million home shopping customers based on purchase history.

Data Scientist — CV Library, London, UK — Apr 2017-Mar 2018

- Principal data scientist at job board with 12 million jobseekers.
- Developed recommender system for sending job alerts to candidates, with 9% conversion rate.
- Trained deep learning models (CNN, RNN, LSTM, word2vec, seq2seq) to analyse candidates' CVs and job descriptions, using Google GPU instances.

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- Deployed model to analyse candidates' CVs in real time when they register, giving better candidate experience and a lower bounce rate on the registration form.

Computer Vision Scientist — Veridium, Oxford, UK — Oct 2015-Mar 17

- Managed a project to develop neural network face recogniser, running on Android, iOS and Windows.
- Team of 5 developers and 5 testers/data annotators.
- Trained convolutional neural networks with TensorFlow, able to classify images such as fingerprints or pharmaceutical pill bottles.
- Designed cryptographic measures to protect biometric data (iris, fingerprints).

Knowledge Engineer / Pre-sales consultant — Artificial Solutions UK, Barcelona, Spain — May 2011-Oct 2015

- Developed human-like dialogue systems for use on mobile and in consumer electronics.
- Worked on voice controlled smart home presented at CES 2016 in Las Vegas.
- Made frequent visits to blue chip companies in Silicon Valley and Asia presenting technology to potential clients.

Solution architect — Pattern Science AG, near Frankfurt am Main, Germany — Aug 2009-Mar 2011

- Machine learning for monitoring market sentiment

Research assistant / Teaching assistant — Psychology Dept., Birkbeck College, London — Sep 2008-Jul 2009

- Analysed and processed MRI data sets using Matlab and Perl.

Research assistant — European Synchrotron Radiation Facility, Grenoble, France — Jul-Aug 2006

- Simulated X-ray scattering on atoms using Mathematica.

Research assistant — Center for Applied Mathematics and Theoretical Physics, Maribor, Slovenia — Jul-Aug 2005

- Publication: *Testing adiabatic invariance in separatrix crossing* (Robnik & Wood, 2006).

Education and qualifications

MPhil Computer speech, text and internet technology — University of Cambridge — Sep 2007-Jul 08

- Speech recognition/synthesis, linguistics, language modelling.
- Machine learning.
- Information retrieval and relationship extraction from unstructured text.
- Research project: pronoun resolution with semi-supervised machine

learning.
- Final grade: 71.2% (pass mark: 55%).

MSc Physics, 1st class Hons. — University of Durham, UK Sep 2003-Jul 07

- Research project: simulations of Raman scattering.

4 A Levels, 2 AS Levels — all at grade A (highest possible grade) Jul 2003

- A Levels: Mathematics, Further Mathematics, Physics, Latin.

Other skills

Languages: Spanish (fluent), German (fluent), French (fluent). Mandarin (certified level HSK 2). Russian (conversational).

2 Experience, qualifications, training of others involved in carrying out any test or experiment

N/A

3 Statement of methodology

1. From 1 July 2021 to 15 July 2021 I conducted an investigation into the current state of the technology at the Defendant, the state at the time of the due diligence process, and any changes immediately before or since the due diligence.
2. I have read the due diligence report and reproduced all analyses executed in the report.
3. I have interviewed Dr. Noah Sullivan (author of due diligence report) and Dr. Morgan Parry (CTO at Defendant company) as well as all three remaining employees at the Defendant.
4. I have made copies of the code and data and executed all code on my computer, attempting to reproduce the **accuracy** figures stated in the due diligence report.
5. I have examined the commit history of the **code repository** which shows a timestamp of all modifications to the technology.
6. I took the image sets (Set A and Set B) and calculated the accuracy and other metrics. The results of the experiments I conducted are listed in Appendix 9.

4 List of documents that I have examined, with copies of important extracts

1. Original due diligence report dated 10 December 2019
[REPORT HERE]

2. Emails between the claimant and defendant company from 2019 to 2020.
[EMAILS HERE]

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3. PowerPoint presentation by Defendant dated 2 October 2019
[PRESENTATION HERE]

4. PowerPoint presentation by Defendant dated 16 August 2019
[PRESENTATION HERE]

5. White paper published by Defendant on their website, timestamped 2 February 2019
[DOCUMENT HERE]

5 Details of any literature or other material I have relied upon in making this report with copies of important extracts

[1] Kevin P. Murphy, *Machine Learning: A Probabilistic Perspective* (2012). p23. (footnote)

> *In academic settings, we usually do have access to the **test set**, but we should not use it for model fitting or model selection, otherwise we will get an unrealistically optimistic estimate of performance of our method. This is one of the "golden rules" of machine learning research.*

[2] Gordon Bing, *Due Diligence Techniques and Analysis* (1996)

6 Photographs, drawings, schedules, diagrams, graphs and other graphics

N/A

7 Chronology

1. August 2019 - Defendant company approaches Claimant to discuss investment opportunity
2. October 2019 - Financial due diligence takes place (examining company accounts). This is not within the scope of this report.
3. 2 November 2019 - 6 November 2019 - Dr. Noah Sullivan visits company, evaluates technology and model, and interviews employees.
4. 10 December 2019 - final due diligence report produced by Dr. Noah Sullivan
5. 20 January 2020 - acquisition and investment begins
6. March 2020 - acquisition complete
7. July 2020 - Claimant company noticed that technology was not performing as expected.
8. January 2021 - Claimant company first raised question about information possibly being withheld improperly during the due diligence.

9. 1 July 2021 - I visit Claimant and Defendant company premises in order to investigate the issues in question

8 Glossary of technical terms

Accuracy – in machine learning this is defined as the number of correctly classified instances of data divided by the total number of instances in the data. For example, if a model classifies 199 of 200 images correctly, it achieves an accuracy of 99.5%. It is important for accuracy to be measured on data which was not used to develop a model, to avoid the problem of 'teaching to the test'.

Code repository – a file system which allows changes to be tracked over time. This allows large teams to work on computer programming code together, with all changes being accountable and leaving a footprint. Every change to the code is marked with a timestamp and author. A code repository behaves as an audit trail for a software project.

Confusion matrix – this is a table that shows how well a machine learning model performs when classifying items such as images and how often it makes certain kinds of errors. For example, a model that detects instances of tumours in medical images can make two kinds of errors: it can miss an existing tumour (false negative), or it can sound a false alarm when there is no tumour (false positive). In many cases these two errors have different costs and it is informative to quantify how often these errors occur. We can express the information succinctly in a table called a confusion matrix, as below:

true positives	false positives
false negatives	true negatives

Commit – a single piece of work which is recorded and timestamped in the code repository. A programmer will typically make several **commits** in a day.

Machine learning – the science of programming computers to learn, as humans learn. Just as a human could learn to recognise the letters the alphabet by being shown images of the 26 letters in various forms repeatedly, and being rewarded when they recognise them correctly, a computer program can be written which is able to learn to recognise and categorise images of wind turbines after being shown thousands of examples (**training dataset**) and which is later able to generalise to unseen examples (**test dataset**).

OpenCV, Keras, TensorFlow – these are well-known open source software packages which contain stand-alone code which can be used to process images, such as from a digital camera, and classify them into categories.

Revert – When a computer programmer decides that a **commit** in a **repository** was a mistake, they can 'undo' it. This is called reverting the commit, and is the analogue to the 'Undo' option in a word processing package.

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Training set, validation set, test dataset – in machine learning it is common to divide a dataset up into segments which are used respectively for model development, refinement, and as an unseen test to benchmark the model's performance. It is important that the research team withhold the test set and do not use it while developing the model.

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9 Table of results of experiments

These are the results of the two experiments I conducted using the **training and test datasets**.

Experiment 1

Training dataset: Set A (1800 images)

Test dataset: Set B (200 images. 40 show a defect in a turbine, 160 are defect free)

Model output: 30 images were classified as defect, 170 were classified as no defect.

Confusion matrix:

155 true positives	5 false positives
15 false negatives	25 true negatives

Accuracy: 90%

Experiment 2

Training dataset: Set A+Set B (2000 images)

Test dataset: Set B (200 images. 40 show a defect in a turbine, 160 are defect free)

Model output: 39 images were classified as defect, 161 were classified as no defect.

Confusion matrix:

159 true positives	1 false positives
2 false negatives	38 true negatives

Accuracy: 98.5%