Institution: University of Leeds

Unit of Assessment: 11 Computer Science and Informatics

Title of case study:
Scheduling research leads to optimised cost efficient rail transport - the Tracsis spinout

Period when the underpinning research was undertaken: 1/1/2000 – 31/12/2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Raymond Kwan	Professor of Scheduling Senior Lecturer Lecturer Research Fellow	01/10/2018 – present 01/08/1998 – 30/09/2018 01/01/1989 – 31/07/1998 01/11/1986 – 31/12/1988
Anthony Wren	Emeritus Professor Professor Reader	01/08/2001 – present 01/01/1994 – 31/07/2001 01/10/1989 – 31/12/1993
Ann Kwan	Research Fellow Transport Scheduling Unit Manager Research Fellow	01/10/2003 – 31/05/2006 01/08/2000 – 30/09/2003 01/08/1998 – 31/07/2000
Les Proll	Senior Fellow Senior Lecturer	01/10/2006 – 31/12/2015 01/10/1984 – 30/09/2006
Zhiyuan Lin (Current University of Leeds staff in assessment unit UoA12)	Research Fellow	01/01/2015 – 01/01/2018

Period when the claimed impact occurred: 1/8/2013 – 31/12/2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

Rail transport scheduling research at Leeds University since 2000 produced optimising algorithms and industry-ready software now used by almost all UK train companies and franchise bidders, contributing to cost effective, efficient and reliable rail transport.

The software was commercialised and further developed by Tracsis – a University of Leeds spinout formed in 2004 **[H]**. From 1 August 2013 to 31 December 2020, the minimum total saving for the UK rail industry is estimated at GBP320million. Floated in 2007, Tracsis' market value has grown from GBP41.5million on 1 August 2013 to around GBP210million in 2020.

2. Underpinning research (indicative maximum 500 words)

Transport scheduling research started from the pioneering work of Wren at Leeds in the 1960s. Advances in computing and the privatisation of British Rail in the 1990s were catalytic in the large body of research at Leeds and laid the foundation for exact mathematical Integer Linear Programming (ILP) approaches to solve these difficult NP-hard problems. Two main resources need to be scheduled – train units and train crews. The breakthrough in train crew scheduling research **[1-4]** led to the Tracsis spinout (2004) and flotation (2007), which made substantial impact reported in REF2014. Since then, the impact has grown further, with the percentage of

train operators using the Tracsis crew scheduling software having risen from 70% to 90% and enhanced by new research on the dependent scheduling of train units **[5, 6]**.

Train crew scheduling is managed through a powerful Generate and Select framework **[4]**. The Generate Phase contains the highly complex labour constraints and operational local knowledge, while the separate Select Phase uses the generic set covering model to carry out a mathematical optimisation.

Proof of concept research and industrial trials at Leeds prior to the 2000s (e.g. research led by Proll and Wren under an EPSRC-funded project GR/M23205/01, GBP141,000, 1998-2001) developed advanced solution techniques such as specialised column generation and branch-and-bound strategies. At that time the solver was able to deliver solutions with up to about 100 crew shifts, but the technical requirements and complexity made it impractical for most rail operating companies as the algorithms struggled to solve realistic problem cases (e.g. > 300 crew shifts) reliably within practical time.

To address this, the researchers proposed and tested new meta-heuristic techniques **[4]**, specifically targeting large and complex problem cases. This research made further progress through an EPSRC+AEA Technology grant GR/S20949/01 (Kwan, GBP212,000, 2003-2006). Work on this grant led to a major breakthrough, in a new hybridised algorithm called PowerSolver, capable of solving train crew scheduling problem cases which were previously deemed too large and complex **[2,3]**. The hybridised algorithm uses heuristics to compress problem cases to a manageable size and complexity to solve them more easily and quickly in numerically stable parallel computation.

This large body of research, combining elements from all of the above aspects, led to a new crew scheduling system called TRACS II **[1,3]**, which was then improved further in TrainTRACS incorporating contributions from the Leeds team. The TRACS II system triggered the establishment of the Leeds spin-out company Tracsis.

Train crew scheduling normally takes the train unit schedules as work to be covered, so the process to schedule them is often a critical bottleneck. Apart from potential direct savings on the vehicle fleet, which requires crews to operate, crew utilisation would obviously also be affected. Leeds also has a long history in transport vehicle scheduling research, dating back to the 1960s. Early research mainly adopted heuristic approaches, but since 2010, Leeds has researched an exact mathematical network flow approach **[5, 6]**. The research has been supported by 2 PhDs, an EPSRC funded project EP/M007243/1 (Kwan, GBP577,000, 2015-18) and a First Rail Holdings grant (Kwan, GBP25,000, 2015-20). The research has developed novel branch-and-price techniques **[5,6]** that led to a practical solver called RS-Opt. Passenger seat demands are satisfied in a realistic manner **[6]** when the train unit flows across the network are optimised and balanced. RS-Opt has been trialled by several rail operating companies and rail franchise bidders.

3. References to the research (indicative maximum of six references)

[1] Wren, A; Fores, S; Kwan, A; Kwan, R; Parker, M; Proll, L A flexible system for scheduling drivers. Journal of Scheduling, vol. 6, pp.437-455. 2003. (https://doi.org/10.1023/A:1024854522373)
[2] Kwan, RS; Kwan, ASK Effective search space control for large and/or complex driver scheduling problems. Annals of Operations Research, vol. 155, pp.417-435. 2007. (https://doi.org/10.1007/s10479-007-0203-3)
[3] Kwan RS Case studies of successful train crew scheduling optimization. Journal of Scheduling, vol. 14, pp.423-434. 2011. (https://doi.org/10.1007/s10951-010-0212-y)
[4] Kwan, RS, Bus and train driver scheduling in: Leung JY (ed.) Handbook of Scheduling: Algorithms, Models, and Performance Analysis, Chapter 51, pp.1-20. CRC Press. 2004

[5] Lin Z, Kwan RSK A branch-and-price approach for solving the train unit scheduling problem. Transportation Research Part B: Methodological, vol. 94, pp.97-120. 2016. (https://doi.org/10.1016/j.trb.2016.09.007)
[6] Lin Z, Barrena E, Kwan RSK Train unit scheduling guided by historic capacity provisions and passenger count surveys. Public Transport, vol. 9, pp.137-154. 2017 (https://doi.org/10.1007/s12469-016-0138-7)

Barrena was a Research Fellow (01/04/2015 – 31/10/2015) funded by EPSRC grant EP/M007243/1.

4. Details of the impact (indicative maximum 750 words)

Tracsis plc – from train crew scheduling algorithm to the Leeds spin out:

Although both rail and bus companies were involved from the first stages of the development process, providing expert knowledge and performing trials on our algorithms, the University of Leeds founded the spin-out company Tracsis in 2004 mainly to commercialise its TrainTRACS train crew scheduling software. ScotRail was their first rail client, although all 25 First Bus companies have continued to be BusTRACS users from 2000 to present.
The breakthrough in the PowerSolver hybridised algorithm **[2]** has enabled large and complex rail problem instances to be solved within 30 minutes making it feasible for UK rail companies to adopt TrainTRACS for use in-house.

Significance

1. The scheduling software developed from the research is responsible for mission critical operations planning in many rail companies. While these companies previously relied on staff and time-consuming manual processes to schedule their crews **[A,B]**, the use of automatic optimising software has freed up their time to be more creative in scenario planning. This has the benefit of not only achieving schedules which are the most efficient and robust, but which can also take into account local issues to improve service reliability. Ultimately, the public rail transport users benefit **[A,B]**.
2. The software is now routinely used for short-term rescheduling, due to weather or engineering works **[A,B]**, and to plan the best public transport options at large events such as football match finals. Such scheduling scenarios often involve an acute imbalance of demands across the network, special constraints, and very limited resources. **[B].**
3. Rail franchise tendering is designed to secure the best value and quality of train services for the public. Since 2008, the TrainTRACS software has been used by nearly all shortlisted bidders in all the UK rail franchise tenders, contributing to cost effective, efficient and reliable rail transport. This gives winning bidders the confidence that proposed services are deliverable by crew resources and raises the standard of the services overall **[B]**.
4. Tracsis has provided new employment. As of 31st July 2020, the Tracsis Group employs over 750 full-time-equivalent staff with 17 offices dotted around the UK (Head office remains in Leeds) **[B]**.
5. As evidence of the success of Tracsis, its distinctive contribution and far-reaching impact, Tracsis has won many business awards, recent examples:
   - The prestigious Modern Railways Industry Innovation Award 2017 in the Operations and Performance category **[C]**
   - Megabuyte Quoted25 Awards 2019, 'Best Performing Company - Industry Specific Software'. This award series looks beyond share price for the top 25 best-performing mid-market quoted companies in the UK's Software and ICT Services sectors **[D]**

Growth and reach during the REF period:

1. Tracsis continues to be successful with increasing revenue, profit and number of employees since REF2014 (all figures at year ending 31st July **[E]**):

	2013	2014	2015	2016	2017	2018	2019	2020
Revenue (GBPm)	10.8	22.4	25.4	32.6	34.5	39.8	49.2	48.0
Profit (GBPm)	2.6	4.2	4.5	4.0	4.6	8.3	6.6	4.1
Employees (fte)	138	295	401	644	683	667	777	757

Its market capitalization has increased from GBP41.5 million on 1/8/2013 to GBP210 million in January 2020 **[B,E,F]**.

2. The TrainTRACS crew scheduling software is used under licence by 90% of the UK train companies operating passenger services. For consultancy projects, Tracsis also has partners in the US and an extensive client base in the UK (including freight train clients), Europe, Australasia and North America. **[B]**.

3. Every train operator who has adopted TrainTRACS first conducted pilot trials and evaluated the savings they could achieve. Tracsis estimate overall savings between 2% and 12% over traditional methods **[B]**. Commented in **[A]**, "I think your estimate of 2% to 12% is reasonable for the UK rail sector". With the salary of a UK train driver ranging from GBP32K to GBP50K per annum and crew costs accounting for up to 50% of total operating cost, TrainTRACS has brought huge savings for train operators.

   The UK rail passenger train operating cost, including leasing train units and track/infrastructure access charges, was about GBP6 billion in 2008-09 (McNulty Report, Figure 3.5 **[G]**); we estimate crew cost to be 40%, i.e., GBP2.4 billion per annum. The train companies using TrainTRACS cover about 90% of the UK passenger trains **[B].** Conservatively estimating the savings at 2%, 4% or 8% gives annual savings of GBP2.4bn x 90% x (2%, 4%, 8%) = GBP43.2m, GBP86.4m or GBP172.8m saving p.a. on crew cost to the UK rail industry alone **[A,B]**. At 2% savings, we therefore estimate a minimum of GBP320 million overall savings brought by TrainTRACS to train companies between 1 August 2013 and 31 December 2020; at 4% and 8%, our estimates are GBP640 million & GBP1,280 million, respectively **[A,B,G].** Commented in **[A]**, "an estimate of £43.2m p.a. for the UK rail sector would probably be conservative and the actual figure is likely to be much higher".

4. The consistent savings and benefits accrued from using TrainTRACS have gained Tracsis respect and trust in the rail industry. Commented in **[B]**, "The dependable power of optimisation and quality of results derived from the TrainTRACS algorithms have been key to the success of Tracsis and have earned us respect and trust from the rail industry.". This reputation has enabled Tracsis to expand the TrainTRACS core business to include closely related planning processes of train unit scheduling and train crew rostering, and to related rail problems of performance and safety information management, data acquisition and monitoring, and passenger count surveys. Since 2013, these expansions have continue to grow and now also include traffic data analytics, risk management software, transit and ticketing solutions and event traffic management **[B,F].**

5. Train unit scheduling complements crew scheduling for planning the complete rail operation. Tracsis co-sponsored an EPSRC/Dorothy Hodgkin Scholarship (2010-2014) for PhD research in this. At the same time, Tracsis has developed an interactive manual system framework (TRACS-RS) anticipating the optimisation algorithms out of the research. The PhD research was further advanced and developed into RS-Opt through an EPSRC funded project EP/M007243/1 (2015-2018). Since 2015, the majority of UK train operators have adopted TRACS-RS. In 2019, Tracsis secured customers for RS-Opt, with

a requirement within an existing multimillion pound contract to deliver optimised rolling stock scheduling **[B]**.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[A] Reference letter from the Service Planning Director, First Transpennine Express, 20/10/2020.
[B] Reference letter from the Chief Executive Officer of Tracsis Plc, 20/10/2020.
[C] Modern Railways Outstanding Innovations 2017: https://tracsis.com/news/20170623-tracs-enterprise-wins-modern-railways-industry-innovation-award-/
[D] Megabuyte Quoted25 Awards 2019, https://megabuyte.com/free-to-air/5d0b2ca3e4b02466a6e3f5ac/meet-tracsis-2019-quoted25-best-performing-company-industry-specific-software
[E] Tracsis plc Annual Report and Accounts (2013 to 2020), https://tracsis.com/investors/
[F] Research analysis article on Tracsis, March 2020: https://www.ii.co.uk/analysis-commentary/aim-star-my-kind-company-ii510995
[G] Realising the potential of GB rail – final independent report of the rail value for money study – detailed report", Department for Transport, May 2011 (herein referred to as "the McNulty report"), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/4204/realising-the-potential-of-gb-rail.pdf
[H] Tracsis plc and history: https://tracsis.com/, https://tracsis.com/our-history/