Institution: Loughborough University

Unit of Assessment: C19 Business and Management Studies

Title of case study: Improving Production and Logistics Operations in the Steel Industry

1. Summary of the impact

Loughborough University research into Decision Support Systems (DSSs) has been used to transform the production and logistics operations of the Shanghai Baoshan Iron and Steel Corporation, China's largest steel company. Implementing DSS has resulted in annual savings of around US$20m and a reduction in CO2 emissions of 585,770 tons per year. The company reports that the "tremendous benefits" of the research have extended to improvements in efficiency, product quality, customer satisfaction and management culture. The work won a Franz Edelman Finalist Award in 2013 for Achievement in the Practice of Operations Research and the Management Sciences.

2. Underpinning research

Iron and steel production, an industry crucial to industrialised economies, consists of a series of complex processes. These involve both continuous and discrete material flows, high temperatures, heavy equipment and the consumption of massive amounts of energy. As shown in figure 1, there are several key stages in production – including iron-making, steel-making, continuous casting, hot rolling, cold rolling and further processing – as well as various logistics operations to support the material/product flow inbound, outbound and between stages. Operations planning and scheduling are critical to the efficient operation of the production and logistics system.

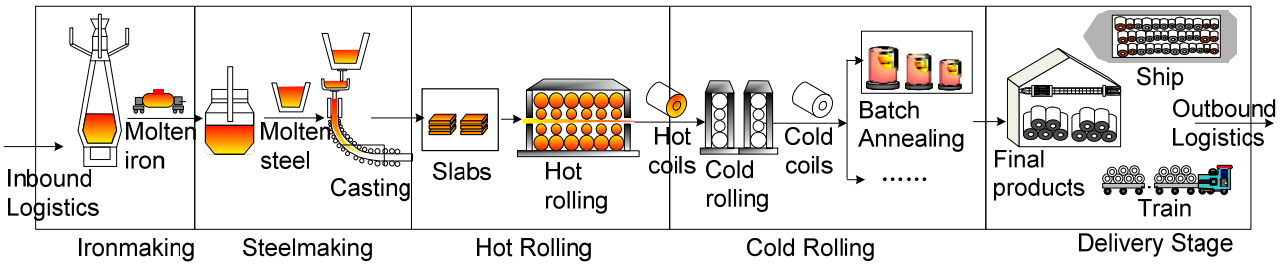

Figure 1. Stages of steel production and logistics system

Professor Jiyin Liu, who joined Loughborough University in 2004, has been working with the steel industry for many years and has been involved in a long-term research collaboration with Lixin Tang, one of his former postdoc research associates and now a professor at Northeastern University in China, in developing optimisation models and algorithms for operations planning and scheduling in various stages of steel production and logistics. After Liu joined Loughborough University the pair set up a collaborative research team and received joint research grants from the National Natural Research Foundation of China **[G3.1]** to further their work in this field. Steel production, which provides materials for manufacturing and construction, is particularly vital to a rapidly emerging economy such as China.

The team, with Liu as a core member, studied decision problems in different phases of steel production and logistics operation, including scheduling of charges and casts in the steel-making and continuous casting stage **[3.1][3.5]**; sequencing in the hot and cold rolling stages **[3.2]**; batching and crane scheduling for the batch annealing process in the cold rolling stage **[3.3][3.6]**; and allocation of berths and scheduling of unloading equipment for ships carrying inbound raw materials **[3.4]**. Optimisation models were formulated for these problems, taking into account practical constraints and considering objectives such as reducing costs and energy consumption, improving product quality and using resources effectively.

The research considered not only academic rigor and novelty but also, more importantly, the feasibility of real applications in practice. To this end, the development of the models was based on analyses of the production and logistics operations of steel companies and the decisions involved.

Data were collected from firms to assist in testing models and algorithms. Among the companies that cooperated with the team was the Shanghai Baoshan Iron and Steel Corporation, also known as Baosteel, the largest steel company in China and one of the largest in the world.

The research team, one of the most active in its field, discovered that some of the constraints experienced by steel companies were problem-specific and others were of standard types similar to those in the travelling salesman problem, knapsack problem and assignment problem. The solutions to the issues identified during the course of the research included deriving optimal properties and valid inequalities and applying techniques such as Lagrangean relaxation and column generation. Tailor-made heuristics and meta-heuristics, including genetic algorithms and tabu search, were also developed. Most of the models involved both integer and continuous variables.

3. References to the research

3.1. Tang, L, Wang, G, **Liu, J** (2007) A branch-and-price algorithm to solve the molten iron allocation problem in iron and steel industry, *Computers & Operations Research*, 34(10), 3001-3015, ISSN: 0305-0548. DOI: 10.1016/j.cor.2005.11.010.

3.2. Tang, L, Wang, X, **Liu, J** (2008) Color-coating production scheduling for coils in inventory in steel industry, *IEEE Transactions on Automation Science and Engineering*, 5(3), 544-549, ISSN: 1545-5955. DOI: 10.1109/TASE.2008.918126.

3.3. Tang, L, Xie, X, **Liu, J** (2009) Scheduling of a single crane in batch annealing process, *Computers & Operations Research*, 36(10), 2853-2865, ISSN: 0305-0548. DOI: 10.1016/j.cor.2008.12.014.

3.4. Tang, L, Li, S, **Liu, J** (2009) Dynamically scheduling ships to multiple continuous berth spaces in an iron and steel complex, *International Transactions in Operational Research*, 16(1), 87-107, ISSN: 0969-6016. DOI: 10.1111/j.1475-3995.2009.00662.x.

3.5. Tang, L, Wang, G, **Liu, J**, Liu, J (2011) A combination of Lagrangian relaxation and column generation for order batching in steelmaking and continuous-casting production, *Naval Research Logistics*, 58(4), 370-388, ISSN: 0894-069X. DOI: 10.1002/nav.20452.

3.6. Tang, L, Meng, Y, **Liu, J** (2011) An improved Lagrangean relaxation algorithm for the dynamic batching decision problem, *International Journal of Production Research*, 49(9), 2501-2517, ISSN: 0020-7543. DOI: 10.1080/00207543.2010.532915.

The research was supported by two research grants from National Natural Science Foundation of China. For one of them [G3.1], Liu is the principal investigator:

G3.1. "Operations scheduling in production and logistics systems", RMB400,000 (≈£40,000), National Natural Science Foundation of China (Grant for collaborative research for overseas young scholars), PI: Liu, J., CI: Tang, L., March 2007 - Dec 2009.

Evidence on the quality of the research

The research has made significant contributions and impact in the area of production-logistics planning and scheduling. The results were published in high level international journals and the publications have received a considerable number of citations. For example, according to Google Scholar, the example papers listed above have received 42 citations collectively up to October 2013.

4. Details of the impact

Loughborough University's work in the field of Decision Support Systems (DSSs) has transformed the production and logistics operations of Baosteel, which, as China's largest and most advanced steel company, employs more than 130,000 people around the globe and was ranked the second most productive steel and iron enterprise worldwide in 2012.

The research team collaborated mainly with mid-level managers and operations planners during the course of its investigative and evidence-gathering work. It noted that Baosteel had advanced

process technology and information systems but had not used them to their full potential in terms of scientific planning: instead planners still made decisions based mainly on their experiences. The team's research demonstrated to the company's management the potential of using optimisation models and algorithms to make decisions, particularly at a time when increased competition and raw material prices compelled the firm to improve its operations management through better use of resources and IT systems.

Managers went on to identify four bottleneck areas across the production and logistics system and decided to improve them by applying the optimisation techniques that emerged from the research. The company collaborated with the research team in implementing the techniques and in developing DSSs for each of the bottleneck areas:

- Integrated charge batching and casting width selection decisions in the continuous casting operation of the steel-making stage
- Open-order slab allocation and slab reallocation decisions in the slab yard of the hot-rolling stage
- Coil batching decisions in the batch annealing operation of the cold-rolling stage
- Ship consolidation and ship stowage planning in the final product delivery stage

The structure of each of these four DSSs (shown in figure 2) is similar. Introduced at the company's Shanghai plant from 2006 to 2011, they have delivered benefits that have been reflected in a series of key performance measures throughout the impact period. For example, it has been estimated that up to 2012 the use of the DSSs at the Shanghai plant resulted in a total cumulative benefit of US$76.81m. It has also been estimated that since 2011 the DSSs have together generated an annual economic benefit of approximately US$20m. Other tangible benefits include an annual reduction of energy consumption equivalent to 293,967 tons of standard coal, an annual reduction in CO2 emission of 585,770 tons and a 9% reduction of inventory. All of these figures have been calculated and/or corroborated by Baosteel **[5.1, 5.2, 5.3, 5.4]**.

The company's Executive President has credited the implementation of the DSSs at the Shanghai plant with improving the productivity of Baosteel's planners more than 30-fold and having a "huge impact" on strategy across the organisation by promoting "the integration of informisation and optimisation" and equipping staff with "invaluable" knowledge. He has confirmed: "The use of DSSs has significantly increased production and logistics efficiency, improved productivity, improved product quality, cut down energy and resource consumption and reduced production and logistics costs." Baosteel has championed the project as the first successful example of the large-scale use of operational research in the Chinese steel industry **[5.3]**. The company's Vice-President for Engineering has highlighted further benefits, including greater customer satisfaction and a shift "from experience-based decision-making to more scientific decision-making" in Baosteel's management culture. The methods were classed "five-star optimisation software" in the company's 2011 systems review, and Baosteel has already made a commitment to implementing the DSSs at its other plants **[5.4]**. As a major state-owned enterprise, the company has also set a precedent for other Chinese firms and industries through its pioneering use of operations research techniques – particularly in light of the fact that China is now the largest steel producer in the world, with its annual output accounting for some 45% of the global total.

Baosteel and the research team jointly submitted the project to INFORMS for the Franz Edelman Award. This is INFORMS' most prestigious award, emphasising real applications of operations research and management sciences and requiring savings and benefits verified by the users. The project won a Franz Edelman Finalist Award at the INFORMS Conference on Business Analytics and Operations Research in April 2013 **[5.5]**.

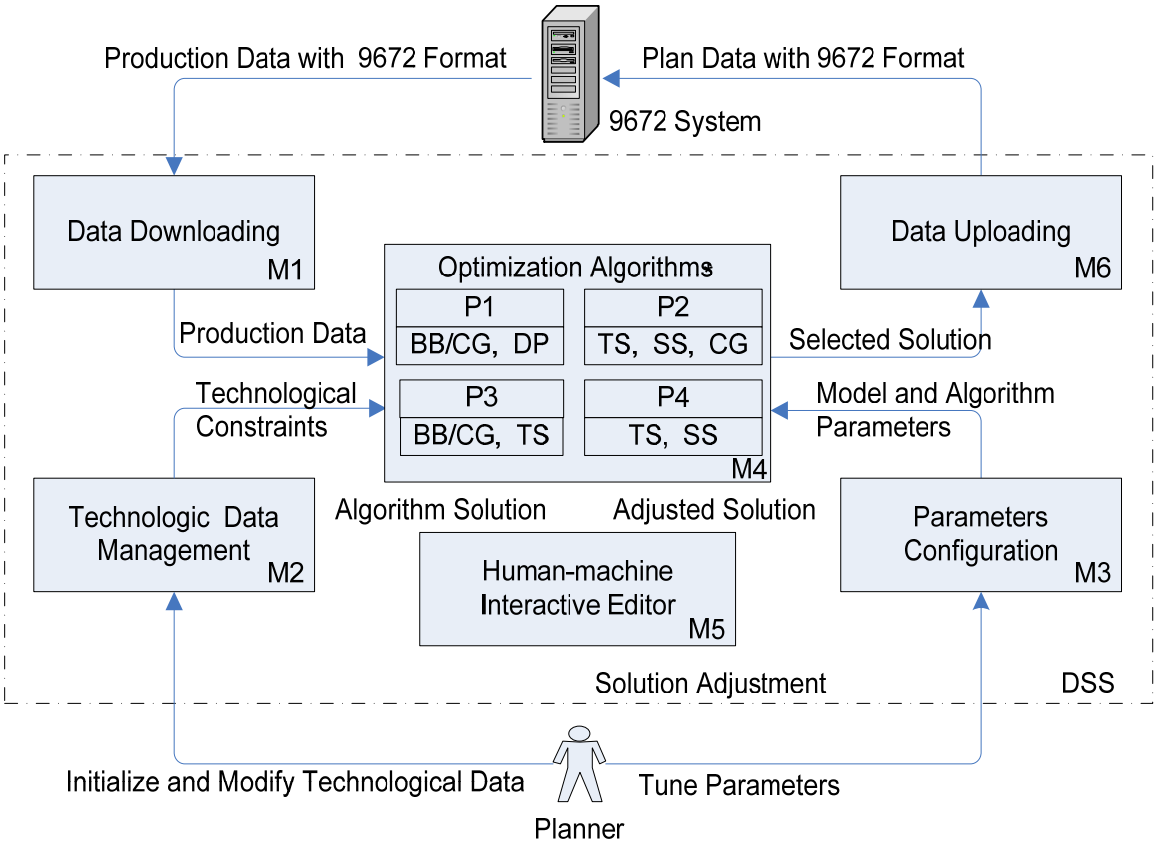

Figure 2. Structure of a DSS

5. Sources to corroborate the impact

The following sources of corroboration can be made available at request:

5.1. Abstracts and details of Edelman Award Presentations 2013, INFORMS Video Learning Center. (https://live.blueskybroadcast.com/bsb/client/CL_DEFAULT.asp?Client=569807&PCAT=6233&CAT=6232).

5.2. Video of speech by the Executive President of Baosteel confirming the benefits achieved and estimating future benefits when the systems are applied to more plants of the company. (http://www.youtube.com/watch?v=4SJGZYLgb4E, the speech is also in the Baosteel presentation on the webpage given in [5.1]).

5.3. Franz Edelman Finalist Award winning paper "Operations Research Transforms Baosteel's Operations", to be published in *Interfaces* (Vol.44, No.1, 2014): http://pubsonline.informs.org/page/inte/forthcoming

5.4. Verification letter from Vice President for Engineering and Technology, Baosteel.

5.5. Certificate of the Franz Edelman Finalist Award to Jiyin Liu.