# RESEARCH
Inside IISE Journals

This month we highlight two articles in *IISE Transactions*. The first article demonstrates the merit of a novel strategy based on trucks' and drones' cooperative delivery, in contrast to either a trucks-alone or a drones-only delivery strategy. A math programming model is set up for efficiently scheduling such cooperative systems, and a branch-price-and-cut solution approach is devised with tailored computation acceleration. This work provides a new way of improving the operational performance in the last mile delivery industry. The second article considers the problem of planning safety stocks in a supply chain where a manufacturer supplies a number of warehouses but has limited capacity. The problem is formulated as a nonlinear mixed-integer program and solved with commercial solvers after convex relaxation reformulation. The authors show that market selection takes on considerable importance when additional capacity is expensive, lead times to bring it online are long and inventory holding costs are substantial. This underpins why the authors raised the earlier question in the first place – i.e., do you really want to serve all your customers? These articles will appear in the March 2023 issue of *IISE Transactions* (Volume 55, No. 3).

## Routing trucks and drones for cooperative delivery

Drone-based delivery has recently become a promising option in last mile delivery. During the COVID-19 pandemic, drones have been increasingly useful because they avoid human contact during the delivery process. However, drones' service range is restricted by battery capacity; their load capacity in terms of weight and volume is limited compared with that of trucks; and their delivery services are constrained by weather conditions and flying altitude restrictions.

The AMP company and the University of Cincinnati jointly developed a novel cooperative delivery system involving both trucks and drones, aiming to compensate for the shortcomings of drone-only delivery. Parcels are delivered by truck groups in this system, consisting of a pair of trucks, and a drone is carried by the truck. A customer's parcels could be delivered by either truck or drone. A drone in a truck group is launched from and returns to the truck.

Jiajing Gao

Zheyi Tan

Shuaian Wang

Roberto Baldacci

Lu Zhen

An efficient schedule for the trucks and drones in terms of their routes and timing decisions is crucial for the performance of the cooperative system. Mathematical programming has been widely used in vehicle routing and has the potential to create a decision model and an efficient algorithm for this cooperative delivery mode.

In their paper, "Branch-Price-and-Cut for Trucks and Drones Cooperative Delivery," Lu Zhen, Jiajing Gao, Zheyi Tan from Shanghai University, Shuaian Wang from The Hong Kong Polytechnic University, and Roberto Baldacci from Hamad Bin Khalifa University show the advantage of the truck-and-drone based cooperative delivery mode by comparing with the traditional truck-alone delivery mode and the alternative drone-only mode in metrics of time and cost. The authors formulated a mathematical program and designed an exact algorithm for routing the trucks and drones and timing their activities so that this cooperative mode can fulfill delivery tasks in time with minimum cost.

Their proposed model considers many practical factors, such as one-on-one collaboration between trucks and drones; truck road network; multiple customers serving requirement; and the flying duration constraints of the drone, among others. For solving the model, the authors designed a branch-price-and-cut based exact algorithm equipped with some tailored acceleration tactics, such as a dynamic programming with calculus approximation, round capacity and subset-row cuts. The experimental results show that these tactics can accelerate the solution speed by nearly 98%. The algorithm empowers the cooperative system to possess the merits of both trucks and drones, leading to a much-improved total performance in the last mile delivery.

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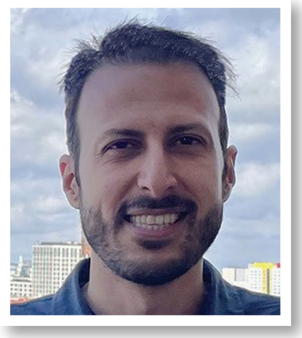
## Do you *really* want to serve *all* your customers?

Supply chains have been in the public eye recently due to disruptions by the ongoing pandemic and the outbreak of war in the Ukraine. Maintaining an economic and reliable flow of goods through a supply chain requires careful coordination of capacity, inventory and logistics assets. Particularly in capital-intensive, high-technology supply chains such as semiconductors, additional capacity is extremely expensive, so firms must be selective in deciding what demand to serve.

In this paper, Foad Ghadimi of OMP in Antwerp, Belgium, and professors Tarik Aouam at Ghent University, Belgium, and Reha Uzsoy at North Carolina State University consider the problem of planning safety stocks in a supply chain where a manufacturer with limited capacity supplies a number of warehouses, each of which, in turn, serves several retail markets.

The manufacturer's lead times increase nonlinearly with resource utilization, thus affecting the amount of safety stock needed to meet demand with a specified service level. The firm must thus exercise care in choosing which retail markets to serve, as committing to meeting demand from many retail markets can result in high resource utilization at the manufacturer, increasing manufacturing lead times for all markets served and thus safety stocks across the entire network.



Foad Ghadimi

Tarik Aouam

Reha Uzsoy

Using the guaranteed service approach, the authors formulate the problem as a nonlinear mixed-integer program, which becomes computationally intractable as the network size increases. To address this difficulty, they reformulate the problem using the proven "all or nothing" property of the optimal solution, yielding a conic quadratic mixed integer program that can be solved with commercial solvers. They also propose a successive piecewise linearization approach which yields the best computational performance on a suite of randomly generated test problems.

The authors show that considering the impact of load-dependent lead times at the manufacturer can yield significant benefits over a sequential approach that first selects markets to serve based on a target utilization level at the manufacturer, then determines safety stocks. Especially for capital-intensive industries, these findings indicate that integrated consideration of queueing behavior, and/or safety stocks and market selection takes on considerable importance when additional capacity is expensive, lead times to bring it online are long, inventory holding costs are substantial and long lead times lead to reduced demand.

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This month we highlight two articles from *IISE Transactions on Healthcare Systems Engineering* (Volume 12, No. 4). In the first, researchers from Germany and the U.S. proposed a data-driven approach to derive the time-dependent value of hospital resources using an optimization model to admit and dynamically schedule patients. They used a large data set of patients treated over one year in a hospital to derive the value of resources under different demand and resource scenarios, and found that the model yields resource valuations that are qualitatively different from conventional approaches. In the second paper, authors from Georgia Tech and Emory University explore the data science challenges in leveraging patient information from telemonitoring platforms. They developed a machine learning model to overcome the challenge of insufficient labeled data that hinders training a robust model for monitoring patients' Parkinson's disease severity. Their proposed model integrates limited samples to build a robust predictive model for disease severity.

## How can hospitals assess the value of their resources?

In any manufacturing or service setting, the incremental benefit of additional resources to revenue is crucial to effective management, supporting a wide variety of decisions such as capacity expansion, short-term resource allocation and patient flow management. The dual variables obtained from linear programming is a classical approach for valuing resources.

However, this approach is generally considered in a static, single-period setting, while hospital resources are used in a dynamic setting, where in each period arriving patients are admitted and then dynamically assigned to resources, according to their clinical pathway. Another difficulty with classical models is that they provide meaningful dual values only for fully utilized resources whose capacity constraints are binding, while queueing suggests that resources that are heavily but not fully utilized can have significant impact on performance measures.

In "Valuation of Hospital Resources: An Optimization Approach Using Clearing Functions," Paul Sutterer and Rainer Kolisch, both of Technical University of Munich, and Reha Uzsoy of North Carolina State University propose a data-driven approach to deriving the time-dependent value of the resources, regardless of whether they are fully utilized. The approach employs an optimization model to admit and dynamically schedule patients on the hospital resources such that the total revenue is maximized. Scarce hospital resources are modeled with clearing functions, which give the outflow of patients as a piecewise linear concave function of the utilization, capturing the impact of congestion and allowing meaningful dual prices for resources that are not fully utilized. The resource values are then obtained from the utilization-dependent dual variables.

Using a large data set containing 17,483 patients treated over one year in a 400-bed hospital, the authors undertake an extensive study where they derive the value of hospital resources under different demand and resource scenarios. The results showed that large instances of the model can be solved in reasonable CPU times, and that the model yields resource valuations that are qualitatively different from conventional approaches.

The approach can be used by hospitals to obtain patient-driven, time-dependent value of their resources, allowing them to make sound decisions on case mix and resource investments, and can also be extended to a variety of other manufacturing and service environments.

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## How can telemonitoring be effectively utilized to monitor Parkinson's disease severity?

Telemonitoring is the use of technological devices to remotely monitor and transmit information about the health status of a patient. The conventional approach to evaluate a patient is to see them during a clinic visit; however, cost, access and logistical issues pose challenges to in-person assessments. Telemedicine and telemonitoring technologies offer possible solutions to address these challenges due to their remote nature, ease of use and the opportunities they provide to make more frequent assessments of the health status of a patient. This provides timely information to physicians to make better and more informed decisions with their patients.

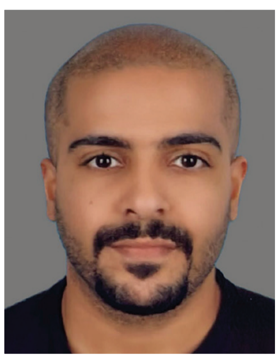
In "A Ranking-based Weakly Supervised Learning Model for Telemonitoring of Parkinson's Disease," doctoral student Dhari F. Alenezi and professor Jing Li from Georgia Institute of Technology and neurologist Dr. Hang Shi from Emory University explore methods to address the data science challenges in leveraging information provided by telemonitoring platforms to benefit patient care.

In the paper, the authors develop a novel machine learning model to overcome the challenge of insufficient labeled data that hinders the training of a robust model for monitoring the Parkinson's disease severity of each patient. Labeled samples of activity data (e.g., tapping, speaking, walking) captured by the patient's mobile phone may be incomplete because of participation, motivation, disease severity or self-reported status, etc., which would limit the ability for a physician to interpret the data collected.

To overcome this, the authors propose leveraging domain knowledge to automatically create weak labels for the unlabeled activity data collected from a Parkinson's telemonitoring platform called mPower. The proposed model integrates limited labeled samples and domain knowledge-based, weakly-labeled

Paul Sutterer

Rainer Kolisch



Dhari F. Alenezi

Hang Shi

Jing Li

samples to build a robust predictive model for disease severity.

The research provides a step toward continuous disease assessments of patients with Parkinson's, thereby providing a tool for physicians to gain insight into each patient's real-life functioning, deliver timely interventions, increase access to care and facilitate improving patient quality of life. These benefits are of high interest, especially to healthcare practitioners and patients in less privileged healthcare systems with limited resources.

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