In 2015, maritime trade reached a total of 9.8 billion tons globally, a volume comprising mostly containers and dry and liquid bulk cargo. Of this total, 4.5 billion tons are dry cargoes (such as coal, iron ore, grains, and bauxite, among other products). This paper examines how the integration of three bulk decision-making problems are of critical importance to ensure efficient operation and use of port terminal facilities. This paper investigates an integrated problem of planning, product allocation, and scheduling, and looks at how the operations research and IT can be applied to find minimal cost solutions, which involve the use of efficient routes and reduction of delays in loading and unloading bulk cargo.

ANALYSING OPERATIONS
A careful and optimized analysis of terminal operations is essential to ensure efficient transport of loads. However, due to fierce competition and increased product flow, optimization cannot be more isolated, i.e., to ensure a competitive differential, low costs and deadlines, all operations and mathematical models involved must be analyzed and solved in an integrated way. The problem investigated herein is motivated by a real case, involving the production planning, product allocation and scheduling of products in the largest bulk port terminal existing in Brazil. The solutions obtained by investigating this problem can be applied not only to bulk ports but also in other operations that involve the flow of cargo between supply, stock and demand points.

In general, the production planning decides when and how many products must be produced, the product allocation establishes the best positions for the products to be stored, and the scheduling takes into account shop-floor settings to determine how the production must be executed. The independent optimization of these problems can lead to non-optimal solutions, thus the need to combine the decisions levels. Integrated methods consider both problems simultaneously that brings better solutions. That is, they produce decisions that offer better gains regarding freight transportation, cost savings, and deadlines.

INTEGRATED PLANNING, ALLOCATION AND SCHEDULING DECISIONS
There are several challenges involved in the optimization of operations in bulk port terminals. Figure 1 highlights the three major nodes related to this problem (supply, stockyard, and demand). The supply node represents the arrival or offer of products to the system. The stockyard is responsible for temporary storage. This storage can be done in sheds outdoors in the case of iron ore, coal and bauxite, or in silos in the case of grains. Finally, the demand nodes represent the destination of the product. These destinations can be the end customer, industries or other cargo terminals. Conveyor belts, wagon turner, stacker and reclaimer equipment, ships and trains are used to transport products between these nodes. As equipment can only carry one product at a time, it is necessary to schedule the tasks to ensure that all goods arrived at the correct destination at the right moment.

The integrated problem of planning, allocation, and scheduling in bulk cargo can be defined as follows: let us consider a
variety of products arriving at a port terminal (supply); they need to be transferred to meet the demand in a set of a pier or to a local storage area (stock). The production planning, allocation, and scheduling problem defines the amount and destination of each product and simultaneously establishes a set of feasible routes to guarantee that the ships will load on schedule.

ADAPTABLE SOLUTIONS
The general problem can be adapted for different applications, such as in the mining industry, where a supply node can be the ore mining, a yard (mineral storage) and demand nodes a railway. In a port terminal where supply nodes are the arrival points of products, a storage yard is the place where the products are stored in the terminal and the point of demand a berth where the ships await loading. In agroindustry, products handled can be grains, such as soy, corn, wheat, and so forth. In goods delivery companies, in which specific equipment receives the products of transport vehicles, these products need storage areas to deliver in to their final destinations.

Optimization problems can be organized into three main modules: production planning, scheduling, and allocation. These three modules are subdivided into sub-problems: lot sizing, blending, berth allocation, bin packing, stockyard allocation, route scheduling, equipment scheduling, yard truck scheduling, and so forth. These are already challenging problems when solved individually, and the challenge is even greater when solved in an integrated way, requiring a significant computational effort.

COMPUTATIONAL TOOLS
We are currently working on designing mathematical models and algorithms that take into account some of these problems. We develop computational tools capable of integrating the planning, allocation, and scheduling problems. Where the primary solutions are related to product flow planning (ore, coal, and grains), selection and allocation of equipment, routes and storage areas, as well as the scheduling of routes and tasks related to loading and unloading cargos. Our solutions are up-to-date with recent technological developments in IoT, data mining, and analytics. Our decision-making tools are focused on the three levels of analytics:
1. Descriptive Analytics: Tools for consolidation of data sources, customized reports about the past operations, describing bottlenecks, delays, and failures. Statistical analysis of loading and unloading cargo, supply and demand
2. Predictive Analytics: Information systems to predict the maintenance plan of equipment and routes, based on its use; reports and analytical tools to help forecast supply, demand, operations, and inventory
3. Prescriptive Analytics: Optimization and simulation algorithms to guide production, scheduling, and inventory, to make sure that deliveries contain the right products at the right time

Adequate investment in technologies and solutions for the optimization in bulk cargo ensures an immediate operational return, reducing costs, fines, anticipating failures, delays, and fluctuations in supply and demand. Technology, innovation and the data revolution can significantly transform the bulk cargo industry, generating challenges and opportunities for all participants.

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ABOUT THE ORGANISATION
Federal University of Minas Gerais is a federal university located in Belo Horizonte, state of Minas Gerais, Brazil. UFMG is one of Brazil’s five largest universities, being the largest federal university. It offers 75 undergraduate degrees, including a Medicine degree, Law and Economics, plus Engineering and Science and Art degrees. It offers 57 PhD programs, 66 MSc programs, 79 Post-Baccalaureate programs and 38 medical internship programs. UFMG has a population of 49,254 students.

The Centro Federal de Educação Tecnológica de Minas Gerais, Brazil, was established in 1910. CEFE-TMG offers to its student a complete academic formation, from the technician to the PhD. Within the institution, students of all levels integrate research groups, share knowledge and are guided by a capable and active teaching staff in all levels of education. The institution is a reference in teaching, research and innovation.

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