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**Research Report**

## A note on challenges and opportunities for Operations Research in hospital logistics

Schriftenreihe Logistik der Fakultät für Wirtschaftswissenschaften der HTW des Saarlandes, No. 2

**Provided in Cooperation with:**

Saarland University of Applied Sciences (htw saar), Saarland Business School

*Suggested Citation:* Melo, Teresa (2012) : A note on challenges and opportunities for Operations Research in hospital logistics, Schriftenreihe Logistik der Fakultät für Wirtschaftswissenschaften der HTW des Saarlandes, No. 2, Hochschule für Technik und Wirtschaft des Saarlandes, Fakultät für Wirtschaftswissenschaften, Saarbrücken

This Version is available at:

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T. Melo

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**Schriftenreihe Logistik der Fakultät für Wirtschaftswissenschaften  
der HTW des Saarlandes**

Technical reports on Logistics of the Saarland Business School

Nr. 2 (2012)

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Saarland Business School

ISSN 2193-7761

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Bericht/Technical Report 2 (2012)

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# A note on challenges and opportunities for Operations Research in hospital logistics

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## Abstract

Ancillary services such as those provided by logistics seem simple and straightforward, yet their role is often overlooked by hospitals. Recent studies indicate that logistics-related activities impact significantly on the quality of health care as well as on hospital costs. Hospital logistics contributes to the provision of care to patients by ensuring that all required services and resources (i.e. staff, facilities, and equipment) are delivered at the right time. In the current context of cost containment, where hospitals must carefully manage public funds, improving the management of these scarce resources has become more and more pressing. Operations Research provides methodologies to support the logistical operations of hospitals and assist in process optimization. In this article we examine the challenges and opportunities faced by operations researchers working in the hospital sector. We also discuss ways of raising the awareness of hospital managers and health care professionals for the benefits of using Operations Research models and solution techniques to improve resource management.

**Keywords:** Hospital logistics; Operations Research; Application areas.

## 1 Introduction

A hospital stay is often an unpleasant experience for a patient. Long waiting times for previously booked appointments as well as delays in diagnosis and treatment are among the most common sources of frustration. Even more striking is the fact that patients seem resigned to accept long waiting times when they seek health care. In a patient satisfaction survey conducted by Ernst & Young in Germany in 2010 [24], waiting time obtained the worst score among all key quality indicators measured by the study. Almost 40 percent of the respondents who had received medical care in a hospital indicated that they were displeased or even very displeased with

this important issue. So why is waiting a pervasive problem in most hospitals and why is it much more common compared with other types of service? Waiting is the consequence of the mismatch between the available hospital resources and the needs for care. This mismatch may be attributed to having insufficient resources to meet demand for health care. But, most likely, the lack of planning, coordination, and communication in delivering health care services is the reason why resources and needs are not adequately synchronized with each other.

Operations Research (OR) provides a wide range of methodologies that can help hospitals and other health care systems to significantly improve their operations. At the same time, many of the complex problems presented by the health care sector also foster the development of new OR methodologies. This article examines the challenges and opportunities faced by OR professionals working in health care operations management. It is beyond the scope of this paper to cover all aspects of health care. Instead, focus will be given to the field of hospital logistics as a means of illustrating the potential benefits of using OR to improve the coordination between supply and demand for health care.

The remainder of this article is organized as follows. In the next section, the role of hospital logistics is described and its relation to operations management is explained. Section 3 highlights the challenges faced by operations researchers in the hospital sector. Opportunities for using OR techniques to tackle problems arising in hospital logistics are described in Section 4. Section 5 illustrates several application areas of OR within the hospital environment. Finally, Section 6 discusses ways of bringing OR into the hospital and of raising the awareness of hospital managers and health care professionals about OR.

## **2 Hospital logistics and operations management**

The provision of high quality health care at an affordable cost is a major challenge for health care systems all over the world. Figure 1 compares the total expenditure on health care among several countries, as a percentage of the gross domestic product (GDP), [1]. In recent years, health care spending has been rising faster than economic growth in most of the countries depicted in the figure. In many countries, the bulk of annual spending growth is due to increases in the prices of health care goods and services, and the availability of ever more new, often high-cost medical products and treatments. As a result, health care providers are facing ever greater pressure to reduce operational costs without affecting the level and quality of their services. In this context, hospitals are of particular interest as they make up the

largest cost component in the health care system. Potential ways to reduce cost involve a more effective and efficient resource management (that is, making supply meet demand adequately as referred in Section 1). Resources include health professionals (e.g. doctors, nurses), rooms (e.g.

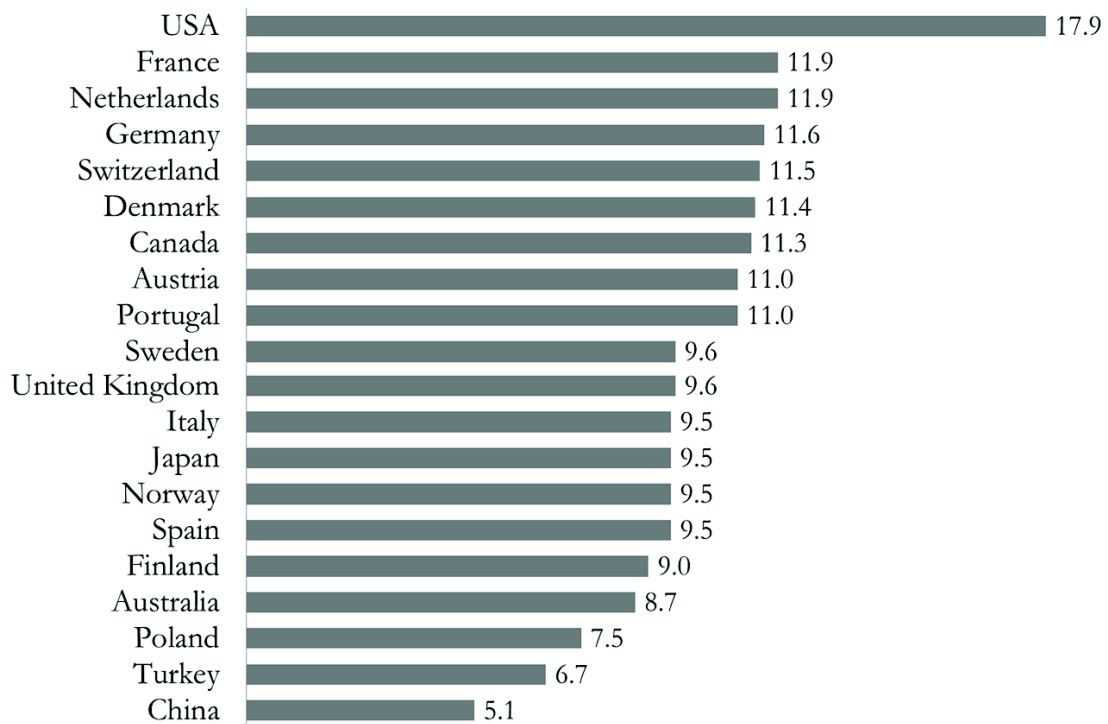


Figure 1: Health care expenditure as a percentage of GDP, selected countries, 2010.

examination rooms, operating theaters), equipment (e.g. x-ray machines, CT scanners), supplies (e.g. blood, bandages), implantable devices (e.g. pacemakers, artificial hips), and instruments (e.g. surgical instruments). Typically, all these health care resources are scarce and so the challenge lies in synchronizing their availability with the needs for care. This entails ensuring that the right goods and services are delivered to the patient in the right place, at the right time, in the right quantity, at the right quality, and at the right price. These five measures are well known as the ‘five rights’ of logistics. They play an equally important role in the health care sector as in commercial industrial settings.

In hospitals, logistics is typically associated with purchasing, storage, transportation, and disposal activities. Material flows comprise e.g. meals, linen, drugs, pharmaceutical supplies, and waste, and are part of the day-to-day logistical operations of a hospital. A recent study conducted by Beaulieu et al. [3] in Quebec (Canada) indicates that logistics-related activities

account for over 40 percent of a hospital's spending. Taking a broader context, logistics is also concerned with patient flows. Planning, coordinating, and controlling the resources involved in material as well as in patient flows are the functions performed by operations management (OM). Hence, similarly to industrial settings, logistics and OM are also two intertwined areas in a hospital. Together, they account for a sizeable portion of a hospital's budget, which is likely to be far higher than the figure reported by Beaulieu et al. [3].

### 3 Challenges in hospital logistics

Despite their importance, the role of logistics and OM is often overlooked by hospitals and other health care facilities. Figure 2 summarizes the key factors. Together, they constitute real challenges to operations researchers.

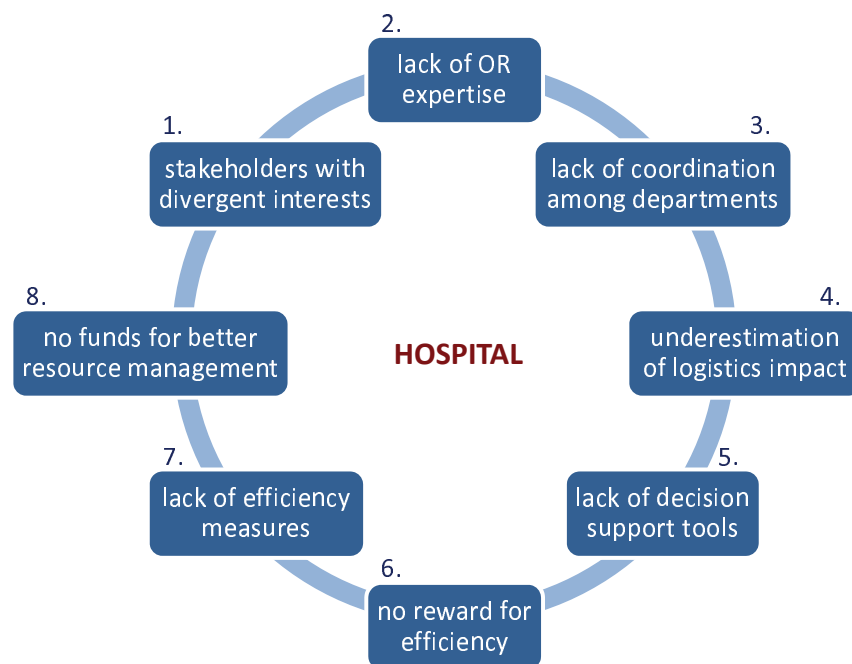


Figure 2: Challenges faced by operations researchers in the hospital sector.

1. In hospitals, decisions involve different stakeholders often having divergent interests: health professionals, administrative staff, and business managers. In German hospitals, for example, these three groups share management responsibilities. While the primary concern of a doctor is the provision of the best possible medical care to a patient, a

manager focuses on reducing service costs and improving resource utilization. Often this leads to conflicting goals.

2. The allocation of resources to departments falls under the responsibility of hospital managers, while the usage of resources is decided by doctors. Typically, these two groups of decision-makers lack the training and the skills to make the best use of the available resources. Although many hospitals are as large as profit-oriented business organizations (e.g. manufacturing companies), it is uncommon to meet a staff member with an advanced analytical education such as operations research.
3. Hospitals essentially operate as a collection of independent departments that compete for limited resources. The coordination of processes within the patient flow is difficult to achieve. For example, in a high-cost unit such as the operating theater, schedules for elective surgeries are usually created without analyzing their effect on other hospital departments such as diagnostic units (e.g. medical imaging and laboratories), nursing wards, and recovery rooms. The lack of coordination results in the underutilization of expensive resources (staff and equipment) and in delays in the patient flow. Moreover, it contributes to increased patient inconvenience due to longer waiting times. Hospitals are not aware of the importance of determining the earliest point in time at which the relevant information becomes available to order resources required further down in the patient flow.
4. Ancillary services such as those provided by logistics seem simple and straightforward and typically, hospitals do not consider them as taking part in their core processes. However, they impact significantly on the quality of health care provided and on hospital costs. For instance, the late delivery of an inpatient to a diagnostic department due to a late booking of the request for transport disrupts the planned schedule of the department and results in reduced patient satisfaction. Often, a new appointment time is set, thus rendering patient waiting time inevitable.
5. In the area of information technology, focus has been given to the development of modern hospital information systems (HIS). These systems are designed to deal with all aspects of information processing in a hospital. In particular, they enable the collection, storage, management, and retrieval of data related to the clinical, administrative, and financial aspects of providing services within the hospital. However, the effective use of the re-

sulting plethora of information to make decisions has received much less attention. Most HIS lack planning tools to support decision making.

6. Hospitals are financially rewarded for how much care they deliver (e.g. the number of hospital admissions, the number of medical tests, the number of treatments) but not for the quality and efficiency in providing that care. In fact, perversely, efforts for improving efficiency all too often carry penalties. For example, in a recent project that we carried out for the intensive care unit of a German hospital, we suggested a number of measures to decrease the time that nurses devoted to ordering and restocking medical supplies. According to the logistics manager, the time saved by the implementation of these measures would result in a reduction of the nursing staff level.
7. Although hospitals are challenged to improve efficiency there is not a consensus on what constitutes efficiency, how to measure it, and what actions to take to improve it. Stakeholders have divergent views of efficiency and goals for efficiency measurement. Furthermore, unlike the private sector, no one really feels responsible for the efficient management of the available resources.
8. At a time of cost containment, it is difficult to convince a hospital manager to divert part of the limited funds away from direct patient care into better resource management.

## 4 Opportunities for Operations Research

The factors described in the previous section present a number of challenges to operations researchers. However, given the experience and background of OR professionals, these challenges can be turned into opportunities. OR has a long history of successful application of advanced analytical methods to help make better decisions in many industrial sectors (e.g. airline, telecommunication, and manufacturing industries). Although health care OR is not a new field the number and impact of OR applications lag behind other service industries. Often, decision-makers claim that health care systems, and in particular hospitals, pose rather complex and dynamic problems compared to those faced by other service industries, thereby hindering the successful application of OR tools. However, complex processes also arise in industrial settings and many OM concepts and OR methodologies have been successfully developed to tackle them. Naturally, it is necessary to identify their applicability to meet the specific conditions encountered in hospitals.

In the field of logistics, hospitals are confronted with challenges similar to the manufacturing industry: efficient resource utilization, cost reduction, improvement of quality of service, control of staff workload, use of new technology, growing demand variability, and increased complexity. Nevertheless, there are also a number of differences between a hospital and a manufacturing environment. For example, the specifications of end products are often subjective and vague in health care (in fact, there is no explicit definition of health outcome). Care is not a commodity that can be stocked. Moreover, market competition is still rather limited, although medical tourism, i.e., traveling abroad to receive medical care, is a growing trend in health care.

In spite of these differences, production control and inventory management concepts can help mitigate the mismatch between supply and demand described in the introduction. This is, for example, the case of the two-bin kanban system that is widely used in industry since it was introduced to the Toyota Production System in the 1950s. The two-bin concept simplifies the process of determining and replenishing supply needs in a nursing ward. The target quantity of a given medical supply is stored in two bins, an active and a backup. When the last item is used from the active bin, a detachable label is placed for reordering. The label identifies the product as well as the replenishment quantity. Labels may be affixed to a wall-mounted rail for scanning (barcode labels) or on a RFID wall panel (RFID tags). During the replenishment lead time each backup bin is used in place of the active bin. Once the medical supplies are delivered to the ward, they are put away in the empty bins and the detached labels are returned to the bins. The specification of the size of a bin for a given medical supply requires the development of an appropriate inventory control policy. Notwithstanding the impressive body of literature dedicated to decision rules for inventory management, the existing knowledge has not been extensively transferred to hospitals yet. This is also the case with knowledge from other OR areas that awaits to be conveyed to the hospital sector.

## 5 Application areas of Operations Research

In the context of material and patient flows, hospital logistics and OM provide a broad range of applications suitable for analysis using OR techniques.

An area that has received considerable attention among operations researchers is workforce scheduling, and in particular, *nurse rostering*. The problem of constructing work timetables for nurses to cover fluctuating demand requirements is extremely difficult. The rosters must satisfy work regulations, distinguish between permanent and casual staff, assign suitably qualified

nurses, distribute night and weekend shifts equitably among nurses, allow for leave and days off, and accommodate a range of employee preferences. Linear, mixed integer and goal programming as well as constraint programming methods have been developed to generate nurse rosters. Real-world problems are often over-constrained so that finding a good quality solution requires advanced heuristics within reasonable computing time. As a result, various metaheuristic approaches such as simulated annealing, tabu search, variable neighborhood search, scatter search, and genetic and memetic algorithms have been proposed, and the number of applications is rapidly expanding. For reviews of the extensive literature on nurse rostering we refer to Burke et al. [5] and Lim et al. [18].

*Appointment scheduling* has also been a rich research area over the past decades, see Gupta and Denton [11]. The process of assigning time slots for serving out- and inpatients arises in diagnostic and treatment units and deals with uncertain service times, no-shows, cancelations, and walk-ins. A good appointment schedule keeps patient waiting times short and minimizes staff overtime taking into account the patient load and the available resources (i.e. staff, rooms, and equipment). Commonly used approaches fall into four categories: mathematical programming (deterministic and stochastic), heuristics, queuing theory, and simulation.

*Operating theater planning and scheduling* (OTPS) has also received much attention in the past 60 years. The strategic (long term) planning level addresses capacity planning given a forecast of patient demand. Typically, surgery rooms and block times are assigned to each surgical department over a given time period. The tactical (mid-term) planning level deals with the creation of weekly/monthly (rough) schedules for elective surgeries. At the operational (short term) planning level, the next day's surgery schedule is generated by setting the sequence of surgeries within each operating room and assigning starting times to surgeries as well as specific resources. Finally, the online planning level deals with rescheduling previously planned surgeries as a result of unforeseen events such as delays, emergencies, and cancelations. The rich and still growing literature on OTPS covers a wide range of OR methodologies (mathematical programming, heuristic approaches, and simulation) for deterministic and stochastic environments. The interested reader is referred to the comprehensive review by Cardoen et al. [8]. The interface between the operating theater and other hospital units (e.g. intensive care, post anesthesia care, nursing wards) is gradually receiving increasing attention, see e.g. Hans and Vanberkel [15].

Strategic operating room planning belongs to the class of *resource allocation and capacity planning problems*. This class involves decisions concerning the mix and volume of patients treated by a hospital and the amount, capability, and type of resources (i.e. workforce and

facilities such as rooms, beds, medical diagnostic and monitoring equipment) for the delivery of health care. *Hospital layout planning* also arises at the strategic level but has received much less attention. The aim is to design a hospital, a clinic or a department so as to minimize the movements of patients and accompanying resources such as medical staff and equipment, see Vos et al. [23]. Quadratic integer programming models were proposed by Butler et al. [6, 7] and Elshafei [10] for problems arising in this area.

As mentioned in the previous section, despite the vast body of literature on production planning and inventory control, the translation of well-known practices into the hospital environment is not as widespread as might be hoped. *Purchasing, distribution, and inventory management* of medical supplies could greatly benefit from OR. Rossetti et al. [21] describe in their recent review the main aspects of inventory management within health care and present techniques and technologies for medical supply logistics.

In the context of patient logistics, planning transports for inpatients among health care units within the hospital has received increasing attention in recent years. *Patient transportation* is a variant of the dial-a-ride problem (DARP) and concerns finding a set of minimum-cost routes and schedules for a fleet of ambulances (or hospital staff) to transport (or escort) inpatients between nursing wards and diagnostic units. Hospital-specific constraints (e.g. different priorities of requests, need for special equipment and assistance of medical staff during transportation, and incomplete knowledge of transport bookings in advance) significantly complicate the development of high-quality vehicle routes and schedules. Route quality is measured by two conflicting criteria, namely the minimization of fleet operating costs and the maximization of patient satisfaction. The latter is often controlled by imposing a limit on the ride time of each patient and on minimizing deviations from the desired times for pickup and delivery. Due to its combinatorial nature, the DARP is extremely difficult to solve and this has fostered the development of new OR methodologies, in particular of new (meta-)heuristics. For example, Beaudry et al. [2] and Kergosien et al. [17] proposed tabu search based approaches, while Hanne et al. [14] embedded an evolutionary algorithm in a software application designed to support all phases of the transportation flow including request booking, scheduling, dispatching, monitoring, and reporting.

While the above list of applications of OR in hospital logistics and OM is by no means exhaustive, it illustrates the wide-range opportunities for OR within the hospital environment. For literature describing the state-of-the-art in health care operations management the interested reader is referred to Hall [12, 13]. A recent review of OR contributions in health care is provided

by Rais and Viana [20]. Vissers and Bleech [22] introduce a number of concepts relevant to OM in health care and illustrate them through various case studies. Brandeau et al. [4] also describe applications of OR in various health care areas. Finally, ORchestra is an online database of the literature in the field of OR/Management Science in health care, [19]. It contained more than 1200 references as of April 2012. A bibliography of operating room management articles is also available online, [9].

## 6 How to bring Operations Research into the hospital?

Hospitals are under increasing pressure to reduce unnecessary costs while improving the quality of the care they provide to patients. In our view, there is much room for OR to improve resource management and thus making supply meet demand for care adequately.

A fundamental requirement for the successful application of OR techniques is a basic understanding of the core hospital processes and the way in which they use resources. There are many protocol-based care pathways for patients with a given clinical profile that define the expected steps to be followed by such patients. However, these protocols are often clinically focused and ignore the interactions between processes and the use of resources. Some years ago, the logistics manager of a large German hospital expressed concern about the long waiting times experienced by patients attending the radiology department. At first, this seemed to be an excellent opportunity to model and solve an appointment scheduling problem for which there is a rich literature on deterministic and stochastic optimization approaches. But, to our surprise there was no description of the characteristics of the activities undertaken by the department and no performance measures had been defined. Understanding how the department operated and collecting data (e.g. on patient arrival processes and duration of appointments) consumed almost all of the time allocated to the project. We focused on mapping processes, identifying inefficiencies, and suggesting ways to eliminate the latter. For example, it was a common practice to assign the same appointment time to several inpatients as a means to avoid idle capacity in case of patient no-show or tardiness. The latter aspect was a consequence of the lack of coordination with the patient transport service for bringing inpatients to the radiology department and escorting them back to their nursing wards.

This case illustrates the fact that it is often not possible or even recommended to use advanced analytical methods to tackle real-life problems. Investing in complex mathemati-

cal models and sophisticated solution approaches whose development may take a considerable amount of time, is not the best way to raise the awareness and gain the confidence of hospital managers and health care professionals. In contrast, it is more effective to start with simple strategies that are not difficult to implement and that are likely to be successful. The combination of analytical thinking and common sense alone can already make a huge difference. At this stage, simulation can be also a useful tool to demonstrate the impact of the new strategies, see Jacobson et al. [16]. The insights gained from this phase help to gradually introduce OR to solve the problems at hand. Thereby, two important aspects should not be disregarded while undertaking a hospital project. First, all stakeholders must be involved and willing to cooperate and embrace changes. A project is bound to fail when the hospital management decides to hire an OR consultant but this decision is not supported by the medical staff. Second, the implementation of new decision support tools should be monitored by operations researchers and particular care should be given to embedding them into the software already in use in the hospital. Finally, it takes significant time and effort to bring OR into practice, but in the end the results will be worth it!

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(43 pages, 2012)

2 T. Melo

**A note on challenges and  
opportunities for Operations  
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Keywords: Hospital logistics;  
Operations Research; application  
areas

(13 pages, 2012)

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Weitere Informationen finden Sie unter <http://logistik.htw-saarland.de>



## **Institut für Supply Chain und Operations Management**

Das Institut für Supply Chain und Operations Management (ISCOM) der HTW ist auf die Anwendung quantitativer Methoden in der Logistik und deren Implementierung in IT-Systemen spezialisiert. Neben öffentlich geförderten Forschungsprojekten zu innovativen Themen arbeitet ISCOM eng mit Projektpartnern aus der Wirtschaft zusammen, wodurch der Wissens- und Technologietransfer in die Praxis gewährleistet wird. Zu den Arbeitsgebieten zählen unter anderem Distributions- und Transportplanung, Supply Chain Design, Bestandsmanagement in Supply Chains, Materialflussanalyse und -gestaltung sowie Revenue Management.

Weitere Informationen finden Sie unter <http://iscom.htw-saarland.de>



## **Forschungsgruppe Qbing**

Qbing ist eine Forschungsgruppe an der Hochschule für Technik und Wirtschaft des Saarlandes, die spezialisiert ist auf interdisziplinäre Projekte in den Bereichen Produktion, Logistik und Technologie. Ein Team aus derzeit acht Ingenieuren und Logistikexperten arbeitet unter der wissenschaftlichen Leitung von Prof. Dr. Steffen Hütter sowohl in öffentlich geförderten Projekten als auch zusammen mit Industriepartnern an aktuellen Fragestellungen zur Optimierung von logistischen Prozessabläufen in Handel und Industrie unter Einbeziehung modernster Sensortechnologie und Telemetrie. Qbing hat auch und gerade auf dem Gebiet der angewandten Forschung Erfahrung in der Zusammenarbeit mit kleinen und mittelständischen Unternehmen.

Weitere Informationen finden Sie unter <http://www.qbing.de>

**ISSN 2193-7761**