

Robotics in ecommerce logistics

George Q Huang^{a*}, Michael Z Q Chen^b and Jia Pan^c

^aDepartment of Industrial and Manufacturing Systems Engineering, the University of Hong Kong, Pokfulam Road, Hong Kong, People's Republic of China; ^bDepartment of Mechanical Engineering, the University of Hong Kong, Pokfulam Road, Hong Kong, People's Republic of China; ^cDepartment of Computer Science, the University of Hong Kong, Pokfulam Road, Hong Kong, People's Republic of China

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Logistics has been the bottleneck in ecommerce, creating problems such as slow and/or wrong deliveries, lost packages, damaged goods and incorrect packing. Automation extends capacities and capabilities as justified by the vast volume of online orders. An automated storage and retrieval system (ASRS) can deliver high efficiency but may be limited in flexibility when it comes to dealing with order disparities in size, shape, weight, volume and mechanical properties. The ASRS may not offer adequate scalability to adapt to growth and cope with increased seasonal demands, or deal with facility breakdowns and carry out technical maintenance. Robotics promises to strike a balance between efficiency, scalability and flexibility. This paper addresses two broad questions: (1) How can robotics create a radical paradigm shift in ecommerce logistics automation systems? (2) Who should be responsible for investing in robotic ecommerce logistics facilities and how should the benefits be shared among key stakeholders? The first question is discussed through recent industrial developments in using mobile robots to achieve robotic picking methods including goods to picker/person (G2P), goods to robot (G2R), robot to goods (R2G), and through the bold concepts of robotic grid warehousing and cellular warehousing (CW). The second question is discussed by extending the emerging concept of the Product Service System (PSS) to propose a Logistics Automation Service System (LASS) business model where stakeholders focus on their own core competencies while complementing each other's expertise and sharing risks and benefits.

Keywords: ecommerce; logistics; robotics; grid warehousing; cellular warehousing

1. Introduction

While the memory of the “Dot-Com Bubble” bursting around the turn of the millennium has not faded away completely,[1,2] ecommerce has still experienced overwhelming success in both developed and emerging economies. The previously predicted major changes in the ways that enterprises in supply chains manage their businesses and consumers do their shopping in the digital economy have now taken place. Significant expansions have been reflected worldwide in the business reports of major ecommerce players such as Amazon, Alibaba and JD.com. What is astonishing? It is the speed at which Chinese ecommerce businesses have caught up in recent years to become a leading ecommerce market in the world. Record-breaking events have been reported with online orders at Double 11 Singles' Day on 11 November year after year.[3] The trend remains strong and the Chinese ecommerce market is projected to be the size of those of the United States (US), the United Kingdom (UK), Germany, Japan and France combined within two decades.[4]

Major ecommerce providers such as Alibaba and JD.com have solved the technological problems of dealing with millions of simultaneous “button clicks” for online orders at their ecommerce service platforms. Online shopping is one thing, but delivery is another challenge. Goods move slowly and damages are a concern. The logistics of fulfilling the massive number of ecommerce orders becomes a critical bottleneck after the order buttons have been clicked. This ecommerce logistics could cost 40% of the price that customers pay for the goods.[5] In the Mainland China in particular, deliveries spent 18% of its GDP, which was almost double the average figure of developed economies.[6]

Ecommerce logistics usually involves three main phases: The first phase involves the replenishment of goods from product manufacturers to the distribution centres and/or warehouses of ecommerce logistics operators. The second phase involves order fulfilment at ecommerce distribution centres through order sortation, picking and packing operations. The third phase involves the fast delivery of orders from distribution centres to customers.

*Corresponding author. Email: gqhuang@hku.hk

The logistics services at the first and third phases are relatively mature, as third-party logistics (3PL) service providers are usually used. However, their capacities may become limited under the extreme demands of concentrated market windows such as during festive and peak seasons. For example, large quantities of the same models of goods are delivered via sea, rail and land transports while high-value small items can be transported by air between manufacturers and distribution centres. Express delivery service providers are usually used for deliveries between distribution centres and customers where the cost of “last mile” deliveries should be reduced and the service could be improved. It is the second phase which creates the bottleneck for ecommerce logistics operators; warehousing operations normally offered by 3PL service providers simply cannot meet the explosive demands of ecommerce transactions in terms of both volumes and varieties of ecommerce orders. Space for storage and order processing is highly limited, especially during peak seasons. Order picking has been extremely labour-intensive and involves long distances of movement for human operators and/or goods.

The investments by 3PL service providers have been increasing in expanding their capacities. Major ecommerce players such as Amazon, Alibaba and JD.com have invested heavily in creating their own logistics facilities, including warehousing and distribution operations. This trend can easily be observed with a quick glance through various reports from openly accessible sources. Businesses have a common expectation for a paradigm shift in ecommerce logistics to reduce, if not eliminate, the bottleneck. Unfortunately, it is not commonly known exactly how such a shift should be implemented. One component of enabling the shift is automation, including the automation of both the flow of information and the flow of materials. The Internet of Things (IoT) and the Physical Internet form the technological infrastructure for automating the flow of information in ecommerce logistics, and there has been considerable literatures with regard to this dimension.^[7] This paper focuses on the automation of the physical flow of materials.

The vast numbers of ecommerce orders seem to justify the automation of warehousing operations to improve efficiency and reduce costs and service times. However, high variety and variability of ecommerce orders make the implementation of automated facilities become complicated. Not only are the type and quantity of content different among ecommerce orders, but their size, shape, weight and surface properties are often different too. These disparities create difficulties in automation. Additional measures must be taken to provide the necessary flexibility to accommodate unavoidable disparities, resulting in high upfront capital costs. Another challenge associated with traditional fixed automation is the limited scalability; that is, an automation system is designed

and created with a more or less fixed capacity which is unable to cope with high demands during peak seasons but becomes under-utilised during off-peak periods. It is also difficult to scale up the automated facilities when ecommerce businesses expand, because the breakdown of one component in the fixed automation may result in the breakdown of the entire system. Maintenance often requires shutting down the whole system. Therefore, a solution must be sought for flexible and scalable automation for ecommerce logistics.

The automated storage and retrieval system (ASRS) has the ability to sort, sequence, buffer and store a wide range of items with high accuracy, efficiency and throughput inventory management capabilities. Such systems operate with a warehouse management system (WMS) and machine controllers. Precision racks allow for high storage density and fast location access. Cranes or shuttles move up and down aisles with accelerated long-distance travel. Load handlers are configured to suit the size, shape and weight of the loads. ASRS allows multi-aisle and multi-level scalability. However, one of the serious limitations of ASRS is that the load handler has difficulties in picking a variable number of items from the same storage location. One possible solution is to replace the load handler with a robot sitting on the shuttle. Alternatively, a robot can be added to extend the functionality of traditional horizontal carousel systems. Robotics promises to deliver flexibility and scalability in terms of automating ecommerce logistics.

Robots have been used successfully in flexible manufacturing factories to perform repeated tasks, mostly at fixed positions, with the required speed, precision and load within working environments that severely challenge human operators. In contrast, logistics operations often involve movement, meaning that robots may have to accomplish their tasks at different positions. Robotics achieves adequate scalability in logistics automation. When an ecommerce business grows, more robots are introduced. Robotics also provides the flexibility necessary for dealing with the vast variety and variability involved in ecommerce orders. Therefore, robotics tackles the problems of the capacities of ecommerce logistics being capital-intensive and the operations being labour-intensive.

Robotics promises an imperative component of the paradigm shift expected in ecommerce logistics. The following two broad questions must be addressed for the shift to take place:

- (1) How can robotics create a radical paradigm shift in ecommerce logistics automation systems? What are the possible approaches and potential impacts?
- (2) Who should be responsible for investing in robotic ecommerce logistics facilities and how

should the benefits be shared among the key stakeholders, including ecommerce operators, 3PL logistics operators and automation technology solution providers?

In order to discuss the first question, industrial developments where robots have recently been used for the purpose of ecommerce logistics are reviewed. Section 2 discusses the use of mobile robots to implement robotic order picking: goods to picker/person (G2P), robot to goods (R2G) and goods to robot (G2R). Section 3 presents a variation of robotic G2P through robotic grid warehousing. Section 4 proposes the bold concept of robotic cellular warehousing (CW). The discussions are based on materials from representative leading technology providers of these robotic solutions.

The second question is discussed by extending the emerging concept of the Product Service System (PSS) to propose a Logistics Automation Service System (LASS) business model where stakeholders such as ecommerce operators, logistics operators and automation solution providers focus on their own core competencies while complementing each other's expertise and sharing risks and benefits.

2. Mobile robots for ecommerce order fulfilment

This section presents two representative solutions of using mobile robots to upgrade warehousing operations: the robotic G2P picking method and the R2G picking method.

2.1. G2P automated order fulfilment

G2P is a commonly used method in which goods are brought to human pickers who complete order picking and possibly packing tasks at fixed positions. In a robotic G2P warehouse, robots are used to move the goods to

the pickers. This solution minimises and possibly eliminates tedious and tiring human movements. Such robotic G2P solutions are commercially available.[8] Examples include the well-known Kiva system owned by Amazon, CarryPick from Swisslog and Matrix Rovers from Symbotic. Robotic G2P solutions not only achieve the necessary degree of flexibility normally offered by manual picking for handling a wide variety and variability of ecommerce orders, but they also enjoy the high efficiency offered by ASRSs. In addition, robotic G2P offers full scalability for dealing with the seasonal and festive fluctuations in demand, as well as business expansions and system maintenance.

For simplicity of discussion, this paper refers to the terms for the components of a typical Kiva system, as used in Amazon warehouses, while generalisation is straightforward for similar robotic G2P configurations. Full details can be obtained from whitepapers about the Kiva system. Research and development (R&D) issues can be found from related literatures.[9,10] As shown in Figure 1, the following key components are involved:

- *Inventory and order (storage) pods.* These include a large number of configurable shelves for storing products that can be different, the same type or a mix. These shelves are not fixed and can easily be carried and moved around the warehouse.
- *Kiva robots.* These mobile robots carry and move inventory pods from their storage locations to target pick stations. Each robot has a screw mechanism that lifts the pod before moving. Each robot uses two cameras to read the barcodes placed under the pods and on the floor grids for navigation. In addition, each robot is equipped with other navigation sensors, including encoders, accelerometers and gyroscopes. Robots communicate with the central control system through messages.

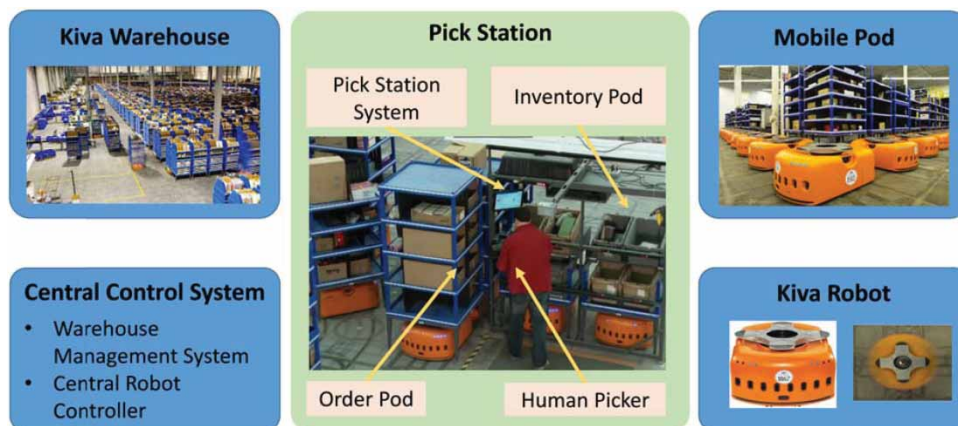


Figure 1. Kiva system: a representative robotic G2P system.

- *Pick stations.* A typical pick station includes a human picker who is assisted by a computer system, one or more inventory pods brought by robots, and one or more order pods that contain order mixes sent away by robots for packing and dispatching.
- *Replenishment stations.* Robots bring empty pods to replenishment stations for building up inventories. Replenished pods with fast-moving goods are generally stored in locations closer to the pick stations and slow-moving goods are kept further away from the pick stations, in order to minimise the search and retrieval time.
- *The warehouse floor is divided into grids marked by navigation landmarks such as barcodes.* These are used to record locations of inventory and order pods. Robots can then search for and retrieve the shelves carrying the required goods. While storage pods are located in the middle of the warehouse, pick and replenishment stations are situated around the perimeter of the warehouse.
- *The central controller.* Hundreds of mobile robots are managed through a powerful central control software system in order to collectively complete order fulfilment: storing, moving, picking and sorting. The system works seamlessly with the WMS, which coordinates order planning, scheduling and releasing. The central controller is a warehouse execution system that orchestrates mobile robots and human pickers to fulfil orders.

A typical working cycle includes several steps. When an order is received at a pick station, the control system locates the inventory pods that carry the items for this order and identifies the robots that are best positioned to move the pods to the pick station. The central controller sends command messages to the corresponding robots. Each robot calculates a path between its current location and the item location, and then moves according to the planned path, taking 90° turns at crossings. When it arrives at the desired location, the robot lifts the inventory pod from the ground and transports it to the pick station. The item space on the rack is highlighted in order to facilitate the human picker getting the item quickly. After scanning the item, the picker puts it in the highlighted box on the order pod. The robot carries this inventory pod to another pick station as assigned by the central controller. Inventory pods carrying other items in the order are similarly processed at this pick station, but they must enter the pick station in a synchronised sequence in order to avoid waiting times. When all items are completed, the picker packs the order and puts it in the order pod. This completes the cycle of fulfilling one order. When all the orders in the order pod are completed, the central

controller sends a robot to take the order pod away for order dispatch.

If a robot replaced the human picker at the pick station in this G2P system, then it would be classed as a G2R system. In this case, the robot must have the picking capability, as in the R2G system, to be discussed below.

2.2. R2G automated order fulfilment

R2G is a new picking method in which a robot moves to a location where goods are stored and picks up the right quantity of the right goods for the purpose of building mixed boxes for ecommerce orders. One typical implementation of this R2G involves an automated guided vehicle (AGV) carrying a robot which picks the required objects, known as the Order Picking Robotic AGV (OPRA) (Figure 2).[11] This combines the mature strengths of the AGV's movement to locate object storage and the robot's ability to pick the right objects. Another variation of R2G is a shuttle carrying a robot in a typical ASRS warehouse. This configuration enjoys the high acceleration of shuttle movements while the robot is able to pick the right items in the right quantities to build the orders.

R2G and robotic G2P share the same fundamental features as the classic P2G and G2P picking methods, with the difference that people are replaced by robots. The number of mobile robots in an R2G configuration would be smaller than that of a robotic G2P configuration. The navigation and control system for R2G can be simpler as there is no need for pick stations in R2G, so space can be better utilised. Robots in R2G can move at a higher speed with the desired stability. If robots in R2G are lightweight, then the total energy consumption can potentially be much lower than that of a robotic G2P system, because goods in storage are not moved in R2G but all storage is moved by robots in G2P.

Affordable robots currently suffer from limitations. Firstly, the current technology requires that objects are

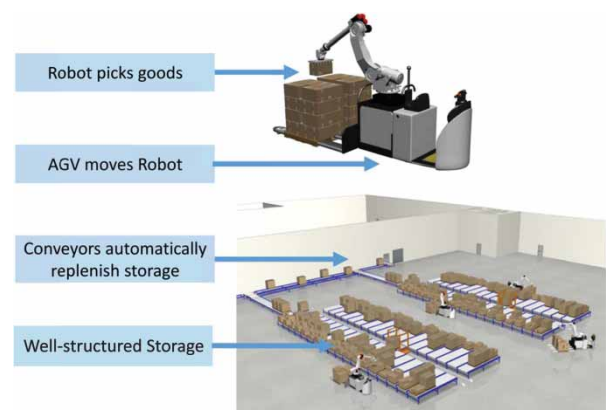


Figure 2. An R2G OPRA (adapted from Bastiansolutions).

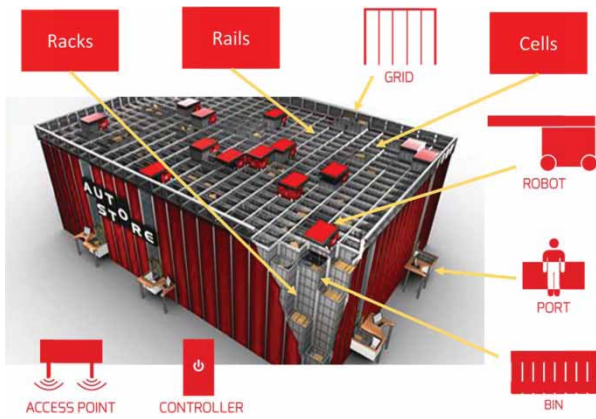


Figure 3. Robotic grid warehousing (adapted from AutoStore).

stored in a highly structured environment so that the robot can correctly handle them with ease. Secondly, a robot's arm end-effector is at present only capable of picking cases, bags, bins and pallets of relatively regular properties, while ecommerce orders are likely to contain objects of different shapes, sizes and weights. Standard boxes have to be used for a universal robotic gripping tool at the cost of reduced space utilisation. Finally, a robot is only effective in locating and handling a stack of boxes containing the same objects; it is not easy for a robot to identify and handle a box containing the ordered object if its neighbouring boxes look similar but contain different objects.

In order to overcome the above limitations, research efforts are being made in the Department of Computer Science of the University of Hong Kong to equip robots with computer vision and visual sensors, with the goal of building a commercially viable automated picking system in unstructured environments. With such technical progress, vision-guided robotic order picking would soon become a reality for ecommerce logistics.[12] To address this task autonomously, the robot needs to execute the following operations sequentially: firstly, it needs to *recognise* the target object from a bunch of clusters. Secondly, it needs to *identify* the desired location of the grasp, e.g. for a martini glass, the desired location is its neck. Then, the robot must *plan* an arm trajectory so that it can approach the object at the desired grasp location. After a motion to approach the object is computed, techniques such as visual serving that align the gripper to the desired location or the haptic feedback can be used to enable the robot to *execute* the picking task successfully. These four steps: recognise, identify, plan and execute, make up the vision-guided robotic order picking pipeline.

3. Robotic grid warehousing

In a typical warehouse, aisle spaces, however compact they are, must be maintained between storage shelves for

shuttles in ASRS, for AGVs/robots in a robotic warehouse, and for manually operated pick vehicles in a conventional warehouse. Such spaces are not utilised for storage. Swisslog's AutoStore [13] is a robotic G2P warehouse that does not need aisle space and hence almost all space is utilised for storage. Because AutoStore uses grids for storage, this type of warehouse is hereafter referred to as a *grid warehouse*.

Robotic grid warehousing provides a special G2P automation solution which combines outstanding storage density and very high flexibility for picking small items. Figure 3 shows a typical grid warehousing configuration. The following standardised modules are involved for simple integration:

- *The grid.* Metal racks create a grid framework with vertical rectangular cells as storage spaces. Each cell holds a number of bins that are stacked directly on top of each other. Rails are installed on top of the grid to allow the fast movement of robots.
- *The bins.* Small goods are stored in standardised boxes or bins, which are stacked in cells of the grid warehouse. Each bin is identified by a unique number in the controller database. Its location in the grid and the goods that it carries are recorded in the WMS.
- *The ports.* Ports are pick stations where items of the same order are picked and packed. These are usually installed in the perimeter of or even below the grid. Robots continuously bring bins to the port to build order boxes. Ports can be used for inbound and outbound purposes, namely, replenishing empty bins with new incoming items and shipping picked and packed orders.
- *The robots.* Multiple autonomous mobile robots move at high speed as guided by the rails mounted on top of the grid. Each robot is equipped with a lift and a gripper for picking, carrying and releasing bins. The robot communicates wirelessly with the control system for commands such as sending a bin to a specific port or recharging in the service area. The locations of the robots are recorded in the database in real time to optimise their movements.
- *The access point (AP) network.* This provides wireless connections between the robots and the control system. Each AP communicates with multiple robots within a range and multiple APs are carefully interconnected to cover the entire grid warehouse.
- *The controller.* This is the central control system of the grid warehouse. Its key functions include the planning and scheduling of robot tasks, recording the real-time positions of bins and robots, integrating with other enterprise information systems, monitoring the working conditions of robots

and components, and sending alert messages for technical services.

When an order is received, it is assigned and scheduled to a port. Multiple robots work together to retrieve and send the bins containing the right items to this port in the right sequence. Each robot leaves this port by bringing a bin back to an optimal location in the grid. When all the goods for the order are picked and packed at the port, the order is then ready for shipment. The controller must synchronise the robots working on the same order for minimising or even avoiding the order's idle time at the allocated port, because ports are limited resources in a grid warehouse.

All bins are circulated within the grid warehouse. Robots bring empty bins to the replenishment (inbound) ports for new items and send them to the best locations, which are optimised by the controller. Robots optimise and relocate bins containing faster-moving items to higher levels so that robots can fetch them more quickly, while slower-moving items are stored in the lower levels. When a slower-moving item at the bottom of the grid is requested, the robots work together to relocate the bins on top of it until one robot is able to access the target bin.

4. Cellular warehousing (CW) with robotics

The robotic automated G2P and R2G solutions presented above offer a certain degree of flexibility for addressing minor but not major disparities between ecommerce orders. In addition, the total distance of robot movements can still be considerable, since picking operations take place across the entire warehouse. One potential solution is to introduce the concept of the cellular warehouse, a concept adapted from cellular manufacturing.

Cellular manufacturing (CM) is a cost-effective approach to implement flexible automation in manufacturing factories.[14] It is based upon the principles of group technology,[15] taking full advantage of the similarity between parts through standardisation and common processing. A CM factory consists of a number of manufacturing cells, each of which can be considered as a small-scale factory. Parts with strong similarities or minor disparities are processed within the same manufacturing cell; parts with few similarities but major disparities are manufactured in different cells. Within each cell, the efficiency of mass production and thus the scale of economy are achieved, while the factory is still able to deal with a wide variety of and variability between products.

Likewise, CW utilises similarities between online orders and/or their items. A few literatures can be found on CW and the work by Shafer and Ernst [16] seems to be an early exploration. A cellular warehouse is composed of multiple sub-warehouses or warehousing cells. Order items with strong similarities are handled within

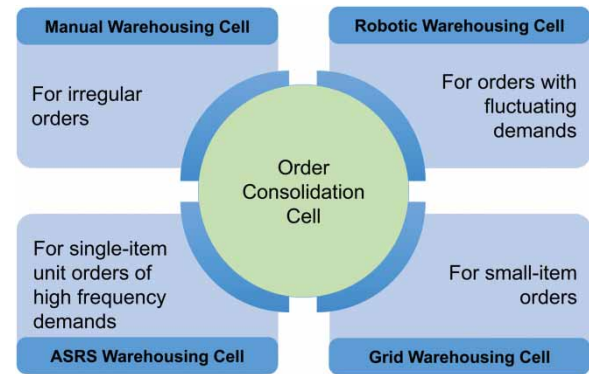


Figure 4. CW.

the same cell. Order items with strong disparities are processed in different cells. The quantity of items handled within each cell is maintained at a high level to enjoy scale-of-economy benefits. Each cell is equipped with appropriately automated facilities, and its layout, space, operations and facilities are optimised for handling similar items without sacrificing overall performance. Each cell is responsible for its own internal control of quality, scheduling, ordering and record-keeping, the same as how a warehouse is operated. In this sense, warehousing cells are different from zones in traditional warehouses, but individual items are picked within the cells rather than within the entire warehouse, the total moving distance is greatly reduced.

Figure 4 shows an imaginary cellular warehouse with different types of warehousing cells. One cell is manually operated and offers the best flexibility for handling irregular orders and/or infrequent items. Another cell is operated under a typical ASRS and offers the best efficiency for handling single items with high-demand frequencies. The third cell is a robotic grid warehouse for small items, and offers the best space utilisation. The fourth cell is a robotic G2P warehouse where human pickers and mobile robots achieve the highest efficiency with necessary flexibility. Among warehousing cells is an order consolidation cell where items are assembled and packed for individual orders. If all items in the same order are handled within the same cell, such an order can be dispatched directly without going through the consolidation cell. One critical issue with the consolidation cell is how to synchronise between cells for processing items in the same order. In other words, items belonging to the same order should enter the consolidation cell within the same time window for packing, in order to avoid waiting times. How consolidation facilities should be configured and operated to achieve synchronisation is open to further discussion and investigation.

The concept of CW is in its infancy and no successful industrial cases have yet been reported. The biggest challenge with its implementation for ecommerce logistics is

how to divide the entire warehouse into cells. An appropriate division should depend on the similarities between items in all ecommerce orders, and this requires analysing the big data collected from recent operations. Similarities or disparities under this context should be considered in a broad sense. For example, for the same goods, a single-item unit and a multi-item unit may not necessarily be considered as strongly similar. Single-item units are suitable for ASRS while multi-item units require other picking methods to build pick pallets. Therefore, factors such as size, shape, weight, unit size, demand frequency and mechanical properties must be considered in order to evaluate item similarities while dividing a warehouse into cells. Indeed, this is an area that requires further investigation.

5. LASS

The PSS is an innovative business model for technology providers to integrate hardware products and services provided by the network of stakeholders. PSS extends the traditional functionality of products by incorporating additional services so that they can jointly fulfil specific customer needs.[17] One of the most successful real-life examples of integrating services into products is that office users are renting, instead of buying, photocopiers. The rental is charged on the utilisation level (e.g. number of copies). Users are guaranteed photocopying functionality during office hours through a pledge of timely repair and maintenance from a service provider. As another example, Rolls-Royce delivers “power-by-the-hour” instead of transferring ownership of the gas turbine engines to the airline companies.

Stakeholders such as ecommerce operators, 3PL operators and robotic automation technology solution providers all want to capitalise on the market growth. However, logistics automation is capital-intensive. Volatile demand fluctuations create uncertainties and risks, forcing all parties to become more conservative. A new business model of ecommerce is needed, and to this end the LASS extends the PSS concept.

Figure 5 shows an overview of the LASS business model. In addition to customers, three types of key stakeholders are involved: one or more ecommerce operators, the ecommerce logistics operator which may be a third party or a subsidiary of an ecommerce operator, and the automation technology solution provider. Customers, other 3PL providers and technology component suppliers are not explicitly depicted in this diagram. Online orders that customers place through the trading platforms of ecommerce operators are passed to the logistics operator. Ecommerce operators subscribe to the services that the logistics operator guarantees for fulfilling and delivering the online orders to customers and replenishing inventories as instructed by ecommerce operators.

Under a LASS business model, the automation technology solution provider is responsible for setting up automated logistics facilities for the ecommerce logistics operator at no cost or at a much reduced concessionary cost, depending on the ownership and revenue-sharing agreement signed between them. The automation provider recovers its return on investments and owns its future profits by sharing the revenue of the logistics operator. In return, the automation provider guarantees that the automated logistics facilities are in good working condition and provides the intended level of

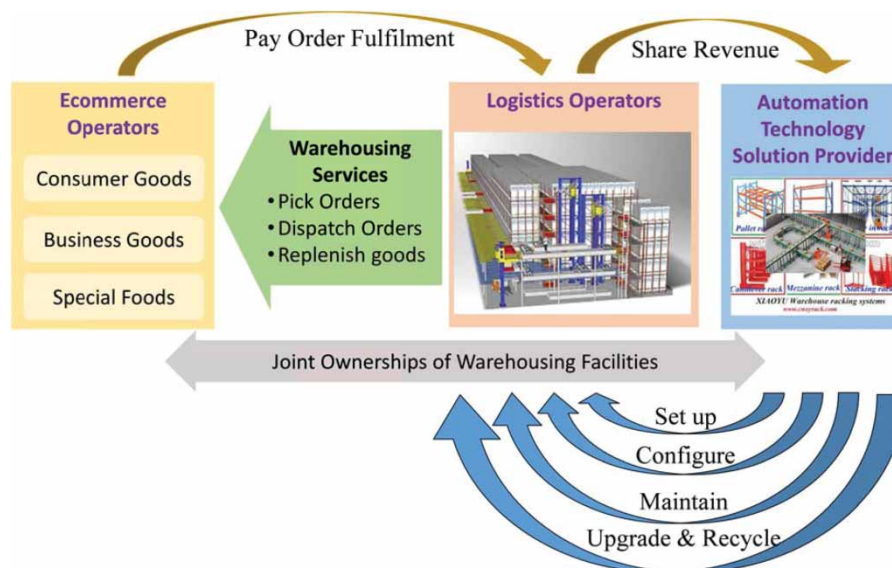


Figure 5. Overview of the LASS business model.

warehousing services and operations. The automation provider has expertise in optimising and configuring logistics facilities with the appropriate mode of automation according to the site space of the logistics provider. The automation provider also has specialised technical skills for monitoring the status of the logistics facilities and providing appropriate technical maintenance and, when necessary, upgrading and/or recycling the software and the physical assets. The logistics operator outsources automation services from the automation provider. Therefore, the logistics operator is able to focus on its core business of supply chain management and warehousing services for fulfilling online orders for ecommerce operators.

A simple calculation of revenue sharing between the ecommerce logistics operator and the automation provider is now described. Let R represent the total income that the logistics operator receives from all ecommerce operators. Assuming that the logistics system works all year round, the total revenue is estimated as $R = r \times n \times O \times 365$, where r is the rate that the logistics operator charges its ecommerce operators for handling one item while fulfilling one online order, n is the average number of items in a typical order, and O is the average total number of daily online orders fulfilled for all ecommerce operators.

Let A represent the total income that the automation provider shares with the logistics operator, and s represent the proportion at which the automation provider shares with the logistics operator for handling one item in one online order. A is then estimated as $A = r \times n \times O \times 365 \times s$. The total cost C incurred to the automation provider over the period of Y years is estimated as $C = F + m \times Y$, where F denotes the total fixed amount of capital investment in setting up an automated ecommerce automation system and m denotes the annual cost of technical maintenance services for ensuring that the system performs its desired functionality. Noting that the operating cost is not included in this calculation because it is incurred on the logistics operator but not the automation provider. In order for the automation provider to break even with $A \geq C$, the number of years can be estimated as $Y = F / (r \times O \times 365 \times s - m)$ given the sharing proportion s , or the revenue-sharing rate $s = (F / Y + m) / (365 \times r \times O)$ given the desired number Y of years to break even.

Based on conversations with an industrial partner as the automation provider about a real-life business case, it can reasonably be assumed that $F = \text{HK\$}50$ million, $m = \text{HK\$}2.5$ million per year, $r = \text{HK\$}3$, $O = 10,000 - 15,000$, and $s = 1/3$. The automation provider breaks even after $Y = 3 - 5$ years. This is indeed a very attractive return on investment (ROI) to the solution provider, while the logistics operator avoids intensive capital investments but enjoys continuous automation

services. Indeed, LASS is a win-win business model for all stakeholders.

6. Concluding remarks

The quality of ecommerce services is currently limited by the logistics bottleneck that creates problems such as slow and/or wrong deliveries, lost packages, damaged goods and incorrect packing. Expanding capacities by creating more logistics facilities and parks would linearly relax, but may not entirely eliminate the bottleneck. Instead, logistics services and operations should be fundamentally upgraded to meet the demands of exponential growth in ecommerce businesses. This paper has discussed how robots enable a paradigm shift to improve the capacity and capabilities of ecommerce logistics. Robotic picking methods include G2P where mobile robots move goods to human pickers, G2R where robots carry out the picking and packing at pick stations, and R2G where mobile robots move to storage areas to pick up goods. Grid warehousing is a special implementation of robotic G2P where aisle spaces are not needed and robots move at a higher speed over rails than along the ground.

Robotic ecommerce logistics automation is highly flexible for managing disparities among online orders. Multiple robots work collectively to bring different items of the same order and deliver them in a synchronised sequence to the pick station to reduce picking costs and increase accuracy and speed. When the business expands, such a solution is scalable as more robots are used in a dynamic, self-organising and adaptive manner. In addition, the overall equipment efficiency (OEE) is very much improved since the breakdown of one robot would not affect other robots, and hence robots can be maintained individually and separately. Finally, when sales are predictable or special offers are planned during festival demands or new incoming orders are dynamically processed, multiple robots automatically move fast-moving goods to areas for instant retrieval for future picking processes.

CW is a new concept where a warehouse is divided into autonomous cells with dedicated facilities so that orders with strong similarities can be fulfilled efficiently, where the similarities are evaluated according to item attributes. Examples of a single cell include a grid warehouse for small items, a manual picking warehouse for irregular goods, an R2G warehouse for regular goods stored in structured environments, a robotic G2P warehouse for goods with certain variety and variability, and a fully ASRS warehouse for handling units. Order components partially picked within corresponding cells are consolidated and packed for shipment. CW further improves efficiency at the cellular level and the flexibility and scalability at the system level.

Robotic automation solutions are capital-intensive. This paper has extended the emerging PSS currently practised in manufactured products to formulate a new business model called the LASS. Under LASS, the automation technology solution provider is responsible for deploying and maintaining the robotic automation facilities, while the logistics operator is responsible for operating these facilities to fulfil ecommerce orders. The automation provider shares the income that the logistics operator receives from participating ecommerce operators. Through the LASS partnership, key stakeholders share investments, benefits and risks.

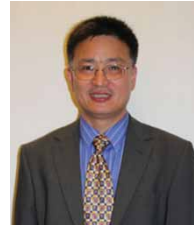
The LASS model is particularly suitable for small and medium-sized enterprises (SMEs) in the business of ecommerce and logistics operations. Large ecommerce players have the financial strengths to lead initiatives in implementing robotic automation solutions. In contrast, SMEs take a more cautious and conservative “wait and see” approach for new technologies to become more mature and for risks to become lower. Some business and technical challenges are yet to be tackled. In both the robotic G2P and R2G solutions, navigation systems are critical for guiding mobile robots to execute tasks at the desired locations. New navigation mechanisms are needed for managing a large number of mobile robots moving to desired locations at high speeds. Computer vision mechanisms are required in order to guide a robot to pick up the correct items in the required quantities at the designated locations. Robots must be equipped with a grasping mechanism that is able to handle goods of wide disparities. Mechanisms are also required for coordination and synchronisation among robots that are involved with handling different items for the same ecommerce in order to avoid waiting times at orders picking and consolidation stations. In CW, further investigation is needed for guidelines and principles on how the warehouse should be divided into cells. Industrial success stories are needed in order for the community to share experiences and lessons. Literatures are extremely limited on the comparative analysis of these proposed solutions in terms of their strengths and limitations. Rigorous findings, rather than commercial promotions, from R&D efforts and field studies are urgently needed to convince sceptics by reducing or removing their doubts.

Acknowledgements

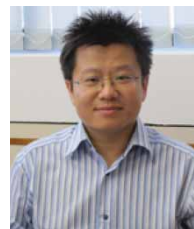
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implementing ASRS for a leading ecommerce operator as an industrial case of the proposed LASS model. We are extremely grateful to the editorial office for their great patience with and encouragement of us in the completion of this paper.

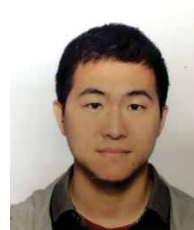
Notes on contributors



Dr George Q Huang is a Professor and Head of Department in the Department of Industrial and Manufacturing Systems Engineering, the University of Hong Kong. He gained his BEng and Ph.D. degrees in Mechanical Engineering from Southeast University (the Mainland China) and Cardiff University (the UK), respectively. He has conducted research projects in the field of Physical Internet (Internet of Things) for Manufacturing and Logistics with substantial government and industrial grants. He has published extensively, including over three hundred refereed articles in journals and conferences in addition to ten monographs, edited reference books and conference proceedings. His research works have been widely cited in the relevant field. He serves as Associate Editors and Editorial Members for several international journals. He is a Chartered Engineer (CEng), a fellow member of the American Society of Mechanical Engineers (ASME), the Hong Kong Institution of Engineers (HKIE), the Institution of Engineering and Technology (IET) and the Chartered Institute of Logistics and Transport (CLIT), and a member of the Institute of International Education (IIE).



Dr Michael Z Q Chen received his BEng degree in Electrical and Electronic Engineering from Nanyang Technological University, Singapore, and his Ph.D. degree in Control Engineering from Cambridge University, the UK. He is currently an Assistant Professor at the Department of Mechanical Engineering, the University of Hong Kong. Dr Chen is a Fellow of the Cambridge Philosophical Society. He is now a Guest Associate Editor for the *International Journal of Bifurcation and Chaos*. His research interests include passive network synthesis, mechanical and robotic control, complex networks and smart grid.



Dr Jia Pan received his BEng degree in Control Theory and Engineering from Tsinghua University, the Mainland China, and his Ph.D. degree in Computer Science from the University of North Carolina at Chapel Hill. He is currently a Research Assistant Professor at the Department of Computer Science, the University of Hong Kong. His research interests include intelligent grasping and manipulation, motion planning, learning from demonstration and planning with uncertainty.

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