
AC 2012-5552: DEVELOPING A STATE-OF-ART SUPPLY CHAIN TEST-BED FOR ENGINEERING EDUCATION AND RESEARCH AT SOUTHERN ILLINOIS UNIVERSITY, EDWARDSVILLE

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Developing a State-of-Art Supply Chain Test-bed for Engineering Education and Research

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Abstract

In today's fierce global competition that forces manufacturing enterprises to produce more complicated, reliable and short life cycle products, there is an urgent need for the SIUE to bring its research and educational focus on product life cycle encompassing from design to retail. To promote this shift of the focus, we have recently developed a unique, multi-disciplinary and state-of-the-art laboratory funded by National Science Foundation MRI grant. The purpose of this paper is to introduce the composition and operation of the laboratory, its initial outcome, and the potential benefits for future engineering education and research.

In order to develop this new facility, we acquired the new equipment including an automatic storage and retrieval system (AS/RS), an intelligent robot, open-architecture conveyor, a programmable logic controller and RFID module, and integrated them with the existing processing and testing equipment in house. Researchers and students can use this facility to catalyze a wide range of cutting edge research projects spanning mechanical, industrial, manufacturing and electrical engineering and to renovate engineering curriculum to practice the theme of the product life cycle in the subsequent effort. These include: (i) studying the impact of RFID on integrated logistics from factory to end-customer, (ii) developing decision support models and tools for strategic and tactical operations in a sensor-enabled supply chain environment; and (iii) analyzing vulnerability and sensitivity of distributed supply chain networks to various disturbances.

This facility can provide a valuable environment for faculty, technical experts and students to work together to develop solutions to manufacturing and supply chain problems in the context of the product life-cycle. Specifically, the laboratory is used as research test-bed and educational platform for faculty and students, by integrating various stages of the product life-cycle including design (CAD) and analysis (CAE), manufacturing (CAM/CIM), warehousing, retailing, and the end-customer interface. Importantly, the laboratory has been designed in a generic manner so that it would allow further additions, which can be available in the future upon technological advancements. For example, the proposed state-of-the-art facility in this project employs *RFID* (Radio Frequency IDentification) technology to facilitate the integration of manufacturing and inventory control by providing efficient and reliable tracking of product flow throughout the system. In a real life setting to produce "chess sets," the students have opportunities to participate in all stages of the product life-cycle including their design, manufacturing, handling and retailing. In this setting, *SIUE Bookstore is a primary retailer of the chess sets*. A Web-server system is used to enable online control and integration of information, production, and cash flows.

1. Introduction

The main goal of this project was to acquire the major components required for a supply chain test-bed and then construct the test-bed using the components. As a result, a unique, multi-disciplinary and state-of-the-art supply chain test-bed consisting of multiple layers to represent customers, retailers, warehouses, manufacturing facilities and suppliers has been constructed in the School of Engineering at Southern Illinois University Edwardsville (SIUE) through the integration of the major components that were acquired using the NSF MRI grant funds. Importantly, the test-bed has been designed in a generic manner to allow technological advancements. Specifically, in this project radio frequency identification technology has been employed to facilitate more efficient and reliable tracking of product flow across the system. In addition, a Web-service module has been developed to enable online control and integration of information, production, and cash flows.

The project outcome can be summarized into three aspects: education, research and service. The test-bed has been used as a key educational platform in summer engineering camp for local high school students from Southern Illinois and Eastern Missouri. Several courses in School of Engineering at SIUE including computer-integrated manufacturing use the test-bed as a whole system or its key components. In addition, the test-bed is currently used as a significant platform for master's thesis research of several graduate students who have been participated in the project activities. The test-bed is also used by researchers and students to catalyze a wide range of cutting edge research projects, for example, (i) studying the impact of RFID on integrated logistics from supplier to end-customer, (ii) developing decision support models and tools for strategic and tactical operations in a sensor-enabled supply chain environment; and (iii) analyzing vulnerability and sensitivity of distributed supply chain networks to various disturbances. After construction, the test-bed started to produce chess pieces in a real-life setting where SIUE Bookstore is a primary retailer. In this setting, customers can place their orders of chess pieces through the developed Web service that will be available on SIUE Bookstore site. Revenue generated by the sales will be directed towards the maintenance and upgrade of the resources.

2. Lab Space Arrangement

Located within the School of Engineering Building, room EB0036 was selected to house the proposed test-bed. Approximately 1,800 sq-ft was designated to represent warehouse and assembly operations of the whole test-bed. Note that another room EB1023 is used to represent manufacturing plant with existing resources like a CNC turning center and a CNC milling center. Before the warehouse module was constructed, a vertical column that provides electrical power (2 points of 220V-3 phase, 4 points of 110V), air source with a filter, data jack for Ethernet connection, etc. was prepared through school work-order. Figure 1 shows the vertical column with air filter, electrical power outlets and Ethernet cables. Note that this vertical column locates in the middle of the conveyor and thus keep the power, air and data source from random access.

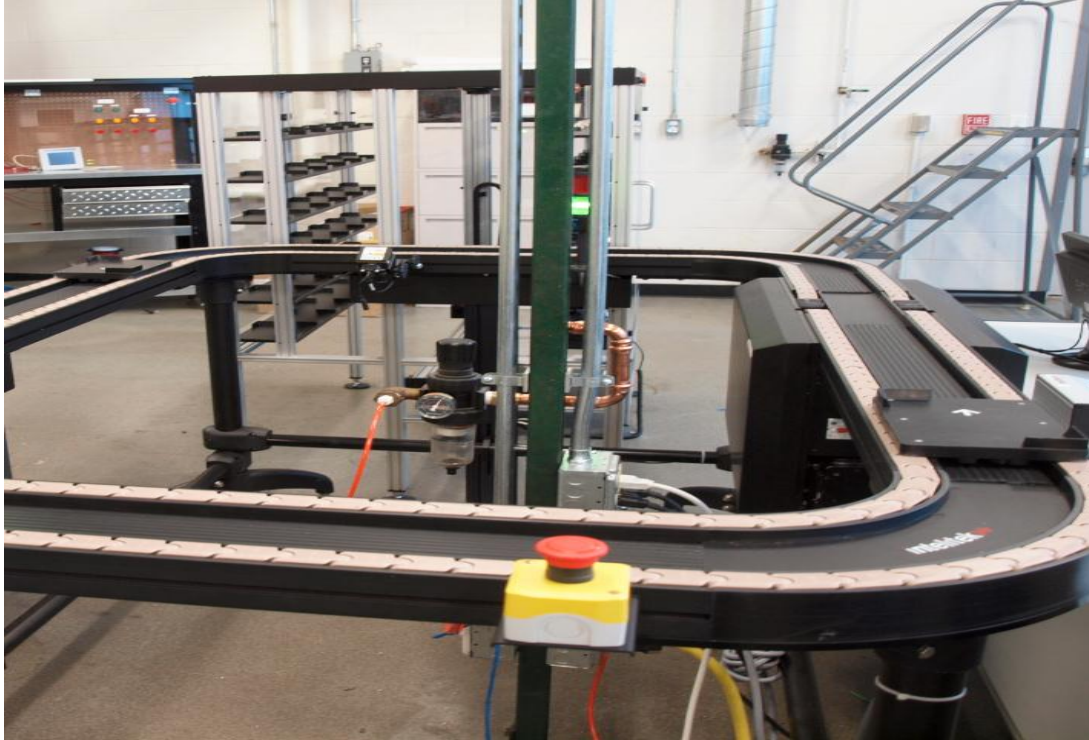


Figure 1: A vertical column that provides electrical power, air source and Ethernet connection for the test-bed of this project

3. Acquisition of Required Components

The required components to construct the test-bed were purchased and acquired through two main vendors, ABB Inc. and Intelitek Inc. as follows:

- An industrial robot from ABB Inc. (Model: IRB140) was purchased as proposed in the project proposal. The robot is versatile with six articulated joints.
- The robot was purchased without gripper and fingers since they are in general highly customized parts depending on the applications. During the project period, one SMC gripper and two fingers were acquired through Flodraulic Group Inc. It should be noted that the pedestal for the robot was fabricated in house.
- Automated storage and retrieval system (AS/RS), reconfigurable conveyor, programmable logic controller (PLC) station, and CIM software were purchased from Intelitek Inc. as proposed in the project proposal. It should be noted that accessories like a working table, 6 pallets and buffer modules were also provided by the vendor.
- Radio frequency identification (RFID) and barcode module for automated data identification were purchased using the support from School of Engineering. RFID module was purchased from Escort Memory Systems (EMS) and the barcode module was acquired from Intelitek Inc.
- A gate through which stock keeping units with RFID tags on it pass by was fabricated. RFID readers with different detection ranges (short, medium and long distance) are placed on the different locations of the gate.

- A Gigabit Ethernet digital camera was acquired using the support of from School of Engineering.
- Three computers (PCs) were purchased to control the entire operations of the warehouse module.



Figure 2: Major components purchased for the construction (conveyor, ASRS, robot controller and robot from the left)

4. Construction of the Test-Bed

In this activity, the test-bed has been constructed using the required components that were acquired as explained in [A.2]. Specifically, it has been constructed in a way to represent various layers of supply chains such as suppliers, manufacturing facility, warehouses, and customer locations as shown in Figure 3. Importantly, the test-bed has been designed in a generic manner to allow further technological advancements. In this project, RFID technology has been employed to facilitate more efficient and reliable tracking of product flow across the system.

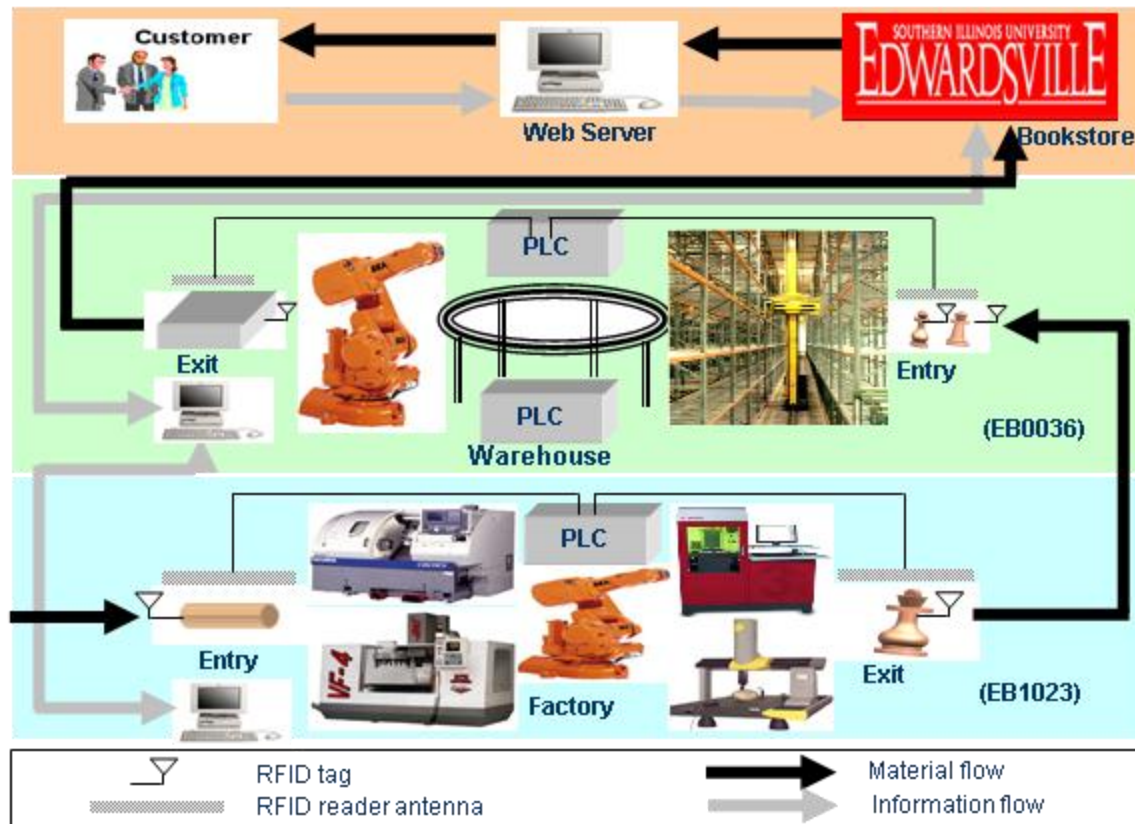


Figure 3: Structure of the test-bed

Hardware: The main focus of this project has been set to construct warehouse layer and supplier layer since a manufacturing facility layer already exists in the School of Engineering (EB1023). The hardware part that has been constructed during the project period, focusing on the warehouse layer, is shown in Figure 4. The figure shows key components of the developed system, which are AS/RS, robot, conveyor, vision and RFID module. In addition, barcode scanner was employed at a location on the conveyor for automated data identification. In the construction activity, six engineering students (five graduate students and one undergraduate student) participated and each student took the responsibility of his or her own module among the key components. More specific activities were performed by participating students including: the design of the robot gripper fingers, the design and construction of RFID gate and its set-up, the design and machining of chess-pieces, the design of buffer module on the conveyor, and the design and fabrication of vision station.

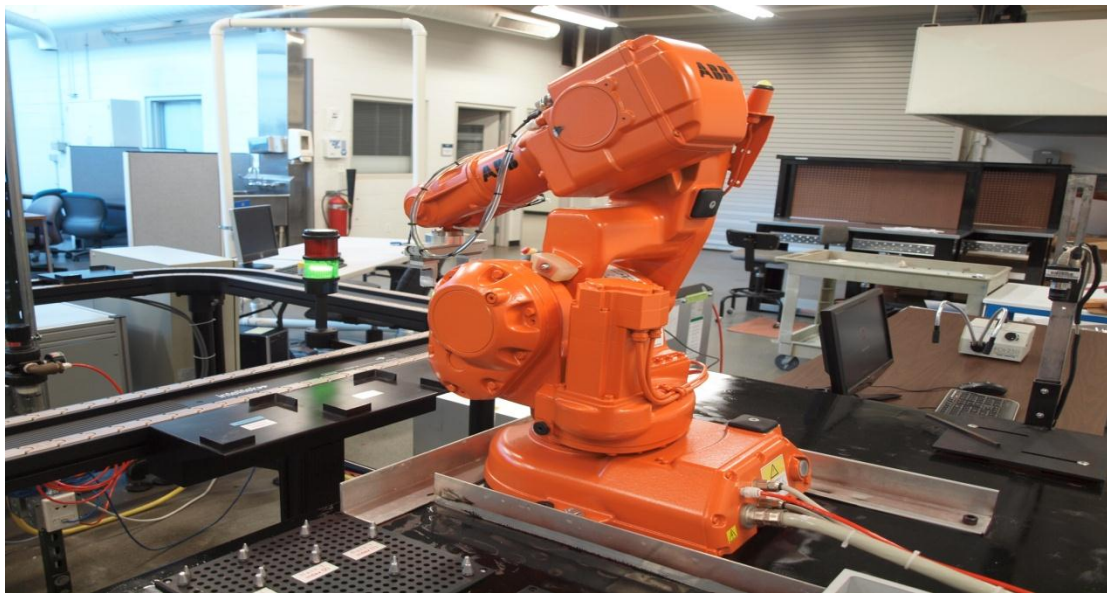
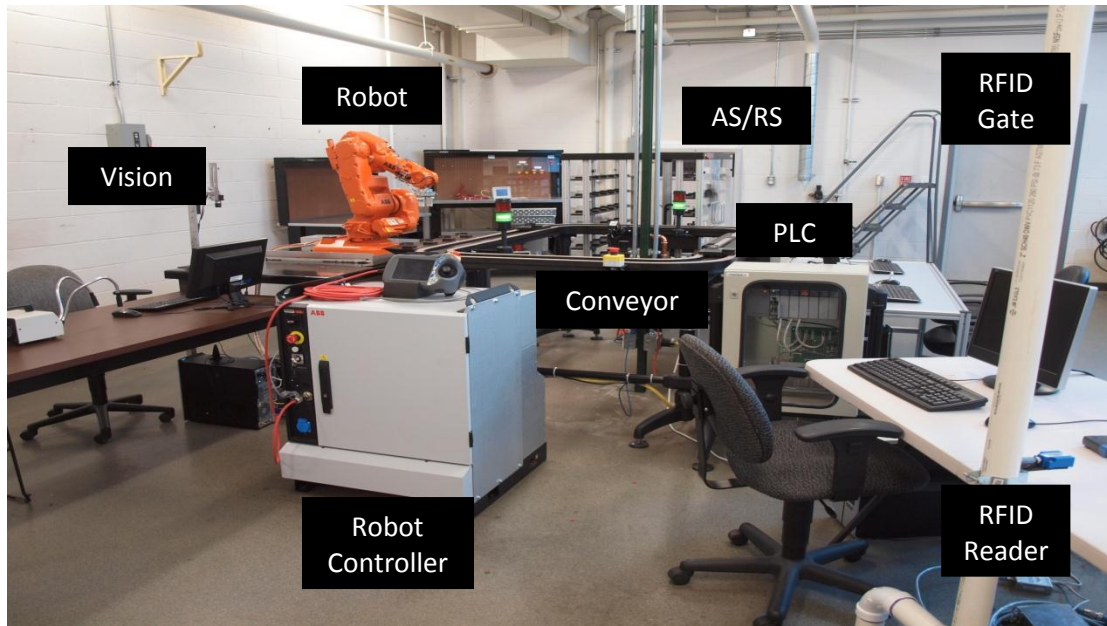


Figure 4: Test-bed constructed during the project period

In the system developed, AS/RS keeps the finished goods inventory as well as raw material inventory. Note that AS/RS has two racks and each rack can store 36 parts. In the AS/RS, a built-in robot arm is used for retrieval or storage operation. The conveyor is used to transport the parts from one station to other station and the programmable logic controller (PLC) controls this operation. Currently, five pallets are operating. Note that the location of pallets on the conveyor is identified by 4 magnets included in the pallet. Theoretically, $2^4 = 16$ pallets can be operating simultaneously. The robot mainly performs loading and unloading tasks. Specifically, it picks up the parts from one location and places them at other locations for inspection/recognition process or assembly process. The inspection station is shown in Figure 5 where left shows design by

student using a CAD software and right shows the real station developed during the project period.



Figure 5: Vision station designed and fabricated by participating students

Note that the vision station shown in Figure 5 is used to automatically recognize if the current part retrieved by the AS/RS is matched to the part ordered by customers. The automatic recognition is accomplished by image processing codes programmed by the participating students.

Software: The main software environment that controls AS/RS, robot, conveyor and vision station is shown in Figure 6.



Figure 6: OpenCIM software that controls the operation of the test-bed

The software called OpenCIM was acquired together with the AS/RS and conveyor from Intelitek Inc. OpenCIM is used for communication among the key components, synchronization of tasks by different components, order-processing, database management and inventory control, etc. Note that the database used in the OpenCIM software environment is DBF. One of the participating students developed a SQL (sequence query language) based database and conversion module between those two databases (Figure 7). In addition, a web-service was developed to enable online control and integration of information, production, and cash flows (Figure 8). Also, a software program that automatically recognizes the types of parts based on image processing was developed by one of the participating students. This program is used to sort the parts out by the robot for assembly process. Robot programs for pick-and-place operations have been developed by participating students using RAPID software (ABB software module) and teaching pendant as well. Note that the students were trained to program the robots for very complicated tasks. Finally, a program to read/write information on the RFID tags was developed. This program accesses the information passing through a gateway that controls the RFID readers. Note that there are multiple RFID readers on the RFID gate of the current system for different coverage area, for example, short (< 1 ft), medium (<3 ft) and long (<10 ft) distance coverage.

SEQNO	PART	ITEMS	FIRSTDO	SEKDO	PRIORITY	TARGET	NOTE	DUE DATE	DUE TIME	DONE
D	ASSEMBLED-PART	1	1	1						
E	VERIFIED-KING	2	1	1						
F	CHECK-VISION	1	1	1						
G	VERIFIED-KING	1								
H	CHECK-VISION									
I	ASSEMBLED-PART									
O	Pans	5								
Q	Queen	2								
	Queen	3								
	Queen	5								
	Queen	10								

Figure 7: Database conversion module

Figure 8: Web-service module for customer order processing

Integration & Training: Integration of hardware and software was performed by the project team including the PIs and participating students with the help of an engineer from Intelitek. The main products of the test-bed are chess pieces with university logos as shown in Figure 9. Note that the test-bed was constructed in a real-life setting and the University Bookstore is a primary retailer. PIs are currently in discussion with the University Bookstore for the sales of these products.



Figure 9: Main products of the test-bed that have been designed and machined by students (King, Knight, Pawn and Queen from the left)

After the system was constructed, a training session for the usage of the system was provided for participating students as shown in Figure 10. A video clip of the completed system and its operation is available at <http://www.youtube.com/watch?v=e7AW20AXGvc>. Appendix summarizes the video clip for the operation of the test-bed.

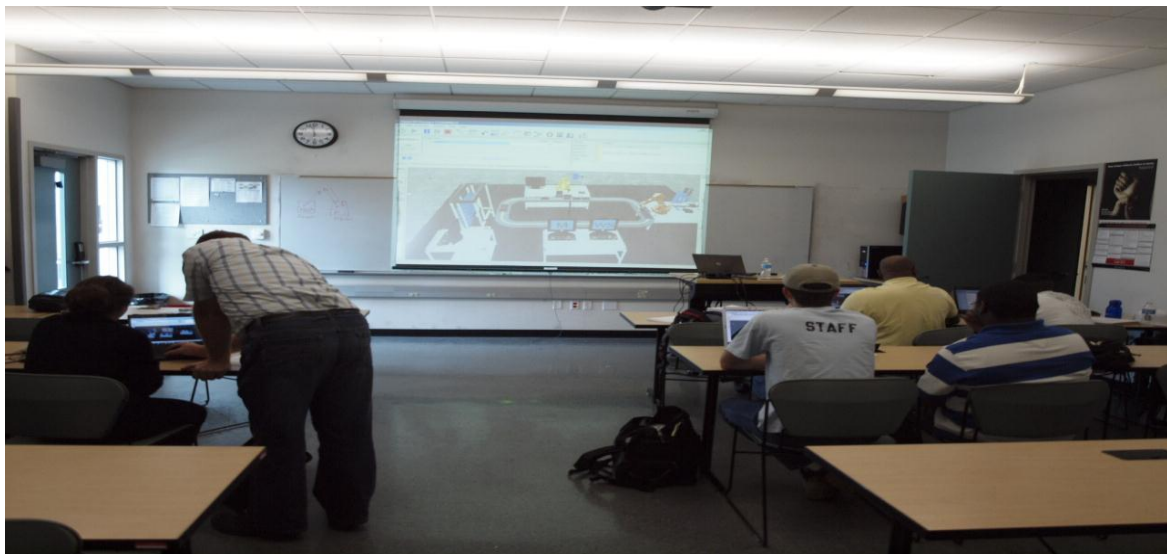


Figure 10: Training session for OpenCIM system

5. Utilization of the Test-Bed

As the utilization of the test-bed increases, significant results and outcomes will be available for dissemination. The test-bed will be used for multiple purposes: research, education, service and entrepreneurship as shown Figure 11.

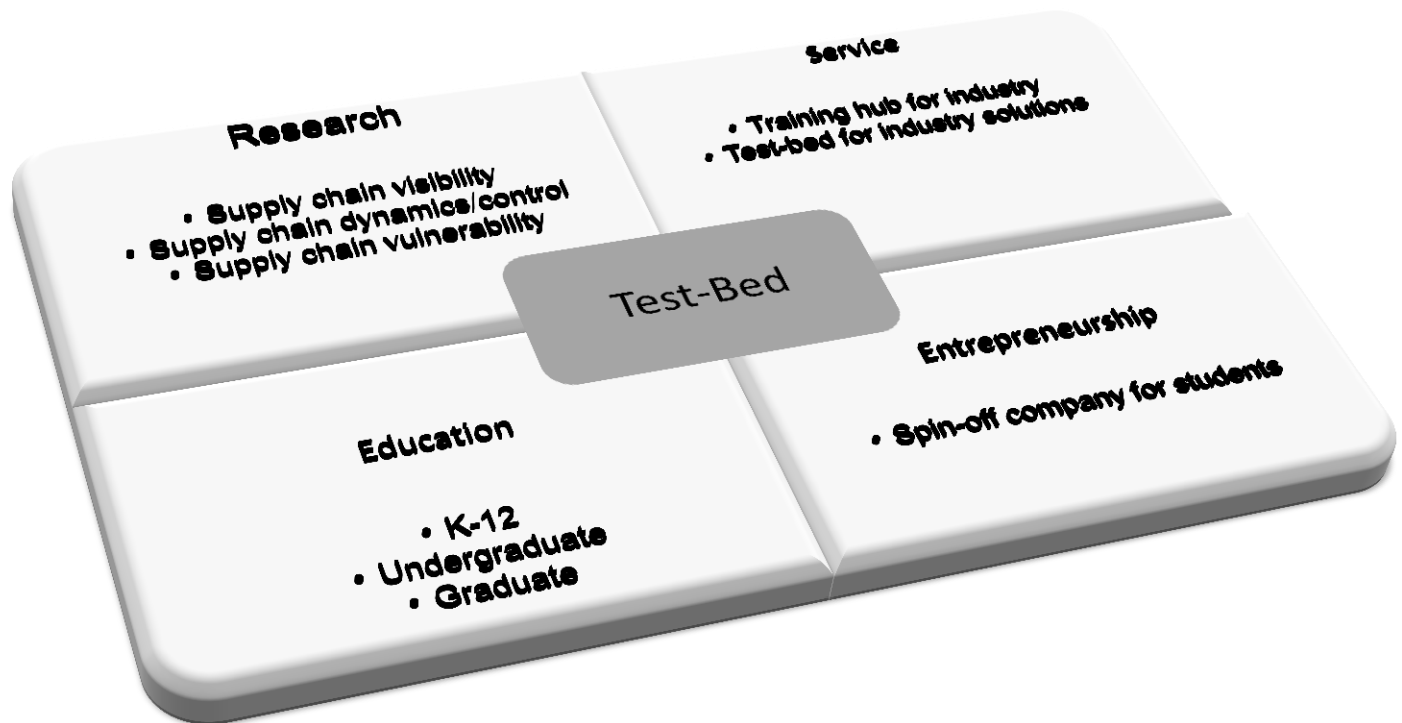


Figure 11: Utilization of the constructed test-bed

The test-bed will help researchers and students catalyze a wide range of cutting edge research projects spanning supply chain visibility, dynamics/control and vulnerability. Specifically, the test-bed is currently used as a key resource for MS thesis work of three students: (i) analysis of complexity in inventory control using information entropy theory, (ii) machine learning based quality control using support vector machine (SVM) and neural networks (NNs), and (iii) design of collaborative service systems including how to handle tasks effectively in dynamic, distributed environments, and how to obtain real-time intelligence through finding/matching data/resources distributed throughout the system.

The test-bed will be used as a key educational platform for diverse groups of students such as K-12, undergraduate and graduate students, who will be exposed to state-of-the-art technology in supply chain systems. Specifically, the PI helped a high school camp (August 2011) with the manufacturing facility layer of the test-bed as shown in Figure 12. In this camp, students learned machining of chess pieces, particularly a pawn piece using machinable wax. In addition, we are on the development of a new course, called Design of Manufacturing Enterprise” that offers

students entrepreneurship experience. In this course, students will represent and be responsible for individual company such as manufacturing company, distribution centers and suppliers. As a next step, the main focus will shift to the integration including operations of the entire enterprises, supply chain management and so forth.



Figure 12: Utilization of the constructed test-bed

The test-bed will also be used as a training hub for companies with different sizes and a useful resource with which those companies can test their solutions for supply chain related problems. To our knowledge, the proposed test-bed constructed through this project is the first supply chain test-bed with the RFID technology employment in the Southwestern Illinois and East Missouri areas. Therefore, this will serve as a core educational platform not only for the engineering students, but also for the students at other universities in the St. Louis metropolitan area, including Washington University, Saint Louis University, University of Missouri-St. Louis, Webster University and McKendree University. Specifically, the Olin School of Business at Washington University in St. Louis currently operates the Boeing Center for Technology, Information and Manufacturing to help students apply their knowledge in supply chains for hands-on projects for corporate partners (<http://bctim.wustl.edu/>). This center supports the view that manufacturing and global supply chain excellence requires a high level of integration among the tasks of product definition, design, marketing, logistics and manufacturing. However, their hands-on projects mostly focus on mathematical modeling, computer simulation and performance assessment, since there is no physical system or test-bed to verify the results. Finally, the test-bed will be spun off to establish a university-wide company (temporarily called “Cougaroar”) that is run by students and sells souvenirs such as special chess sets through the University Bookstore. Revenue generated by the sales will be directed to the “Cougaroar” for maintenance and enhancement of its resources.

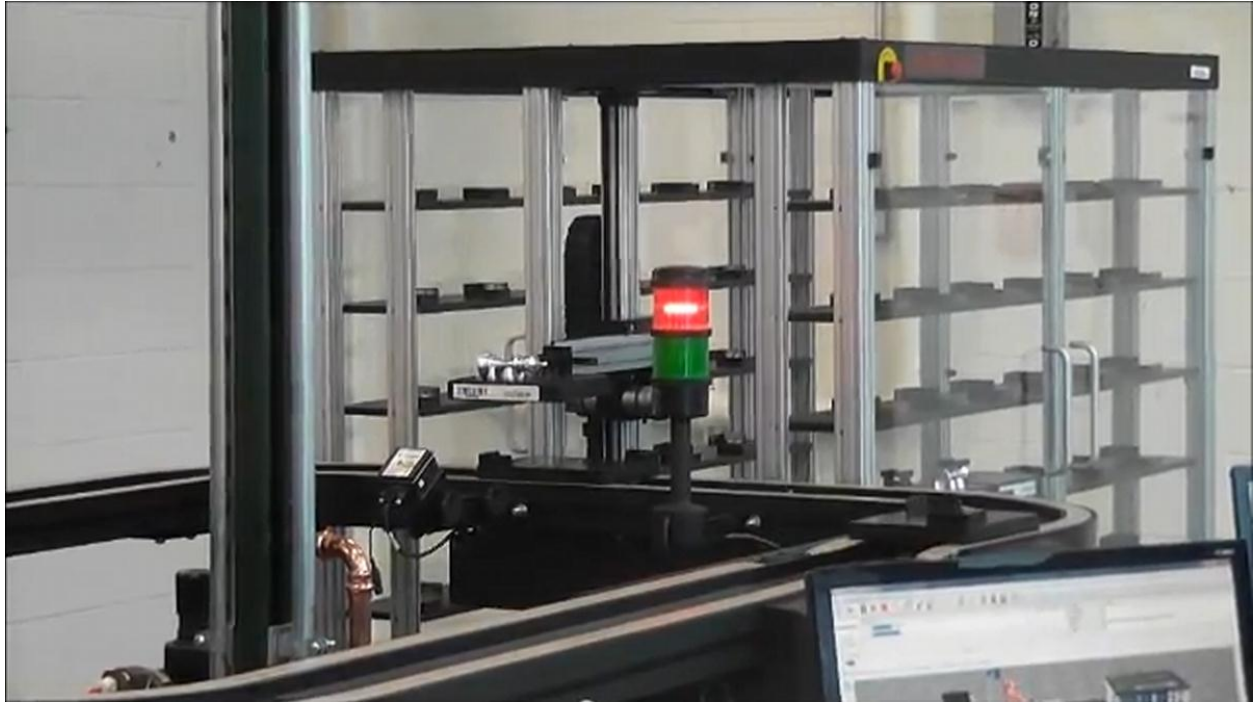
6. Maintenance

One of the participating students in this project has started his doctoral study from fall semester of 2011. The valuable experience he obtained during the project period inspired him to pursue the doctoral study. This doctoral student under the PI’s advising will be responsible for operations and maintenance for several years from now. The costs for the system maintenance and upgrade will be available from the revenue generated from the sales of chess pieces at the University Bookstore.

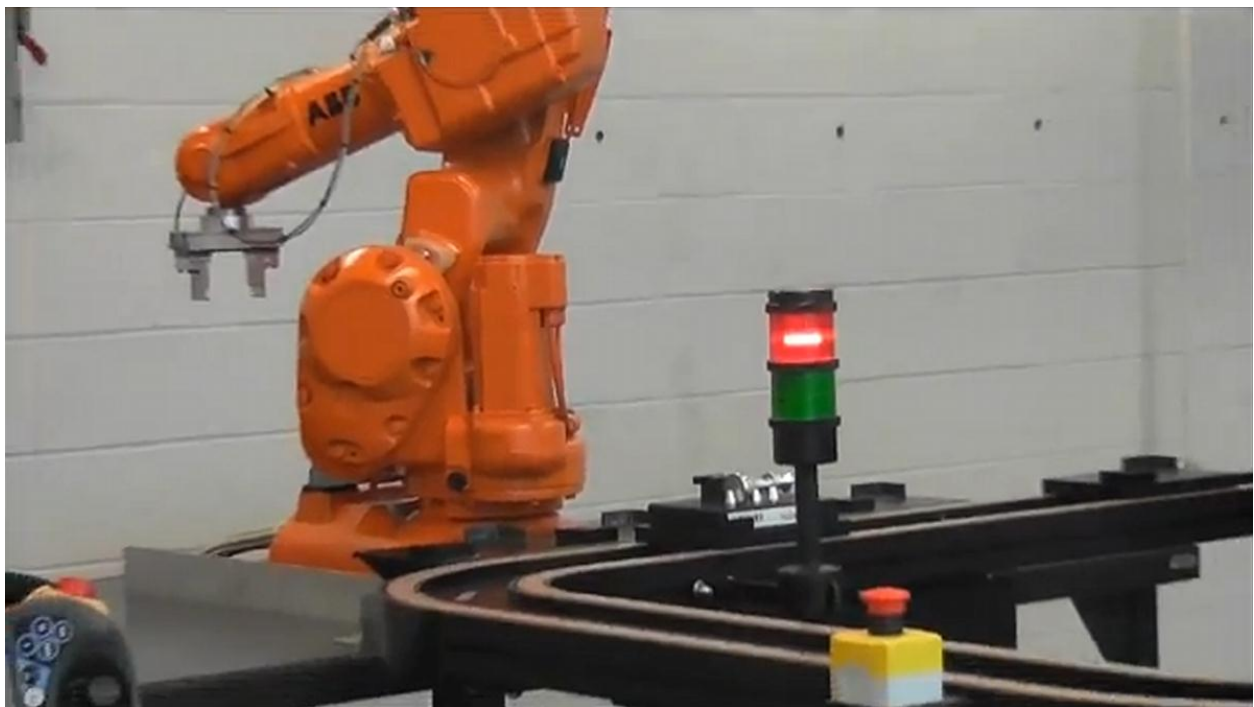
Acknowledgement

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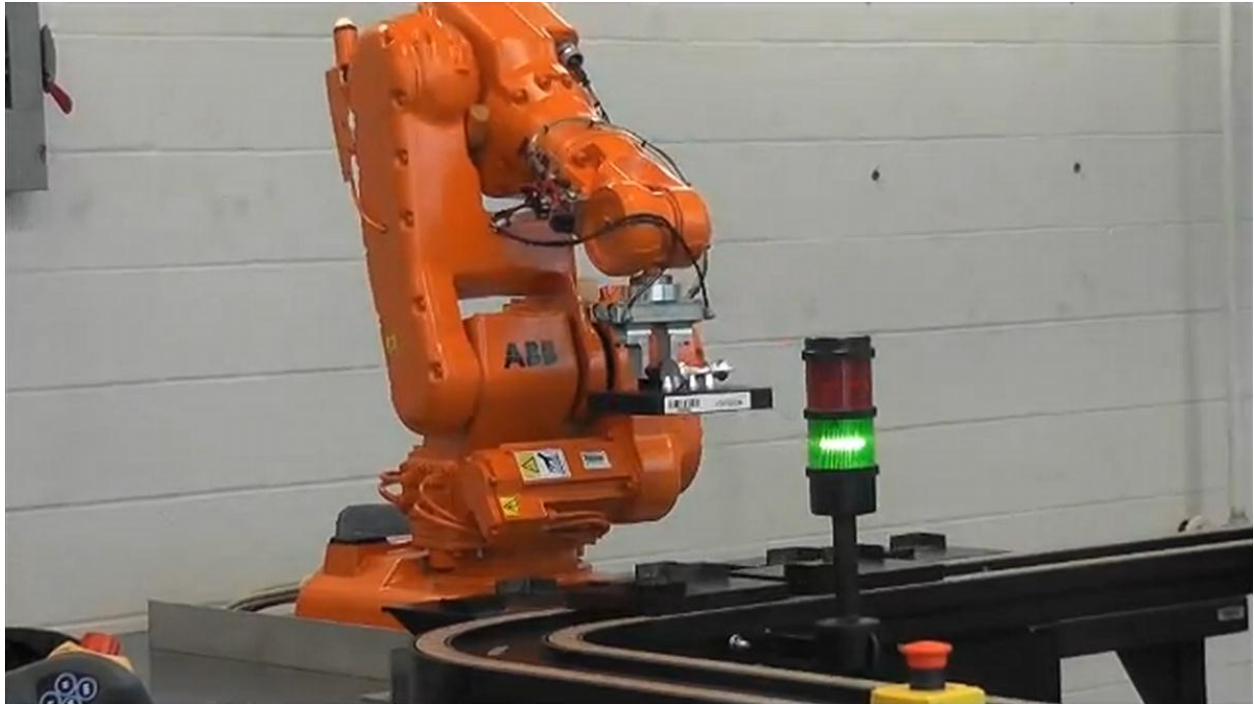
Appendix: Snap shots of the operation of the test-bed



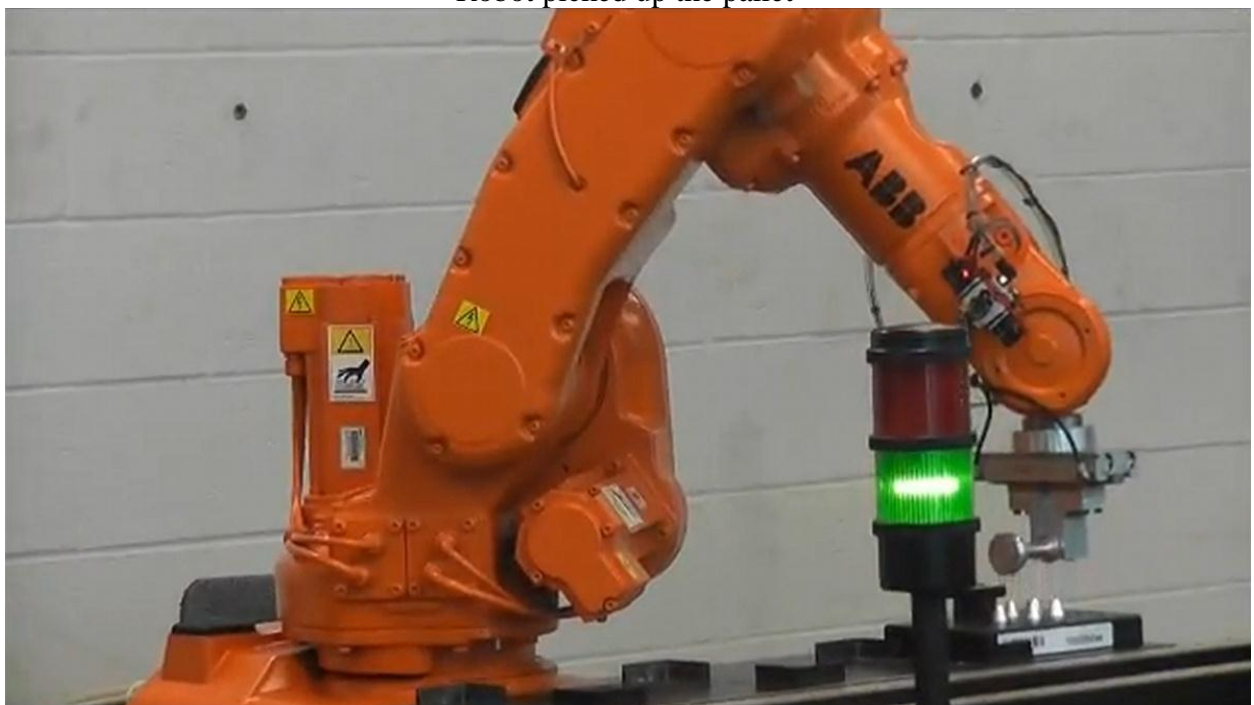
Order initiated and a robot arm in AS/RS picked up the part, and barcode scanner reads the part label



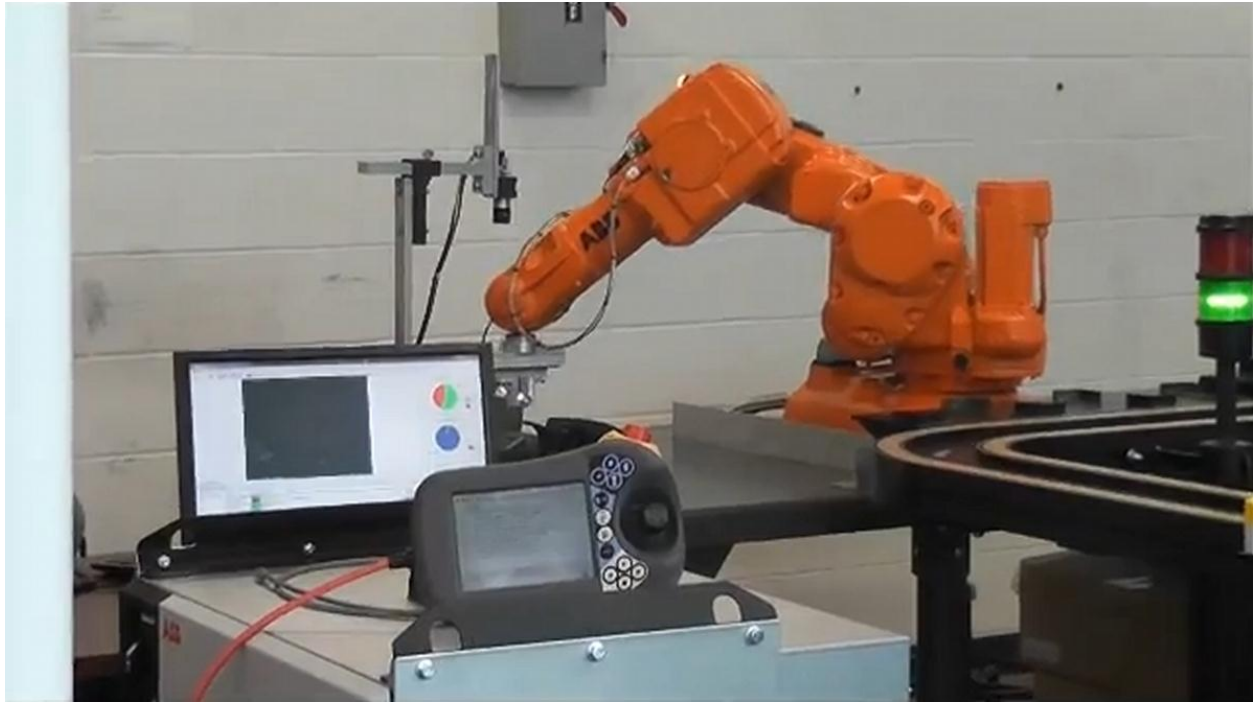
A pallet with a part arrived at robot station



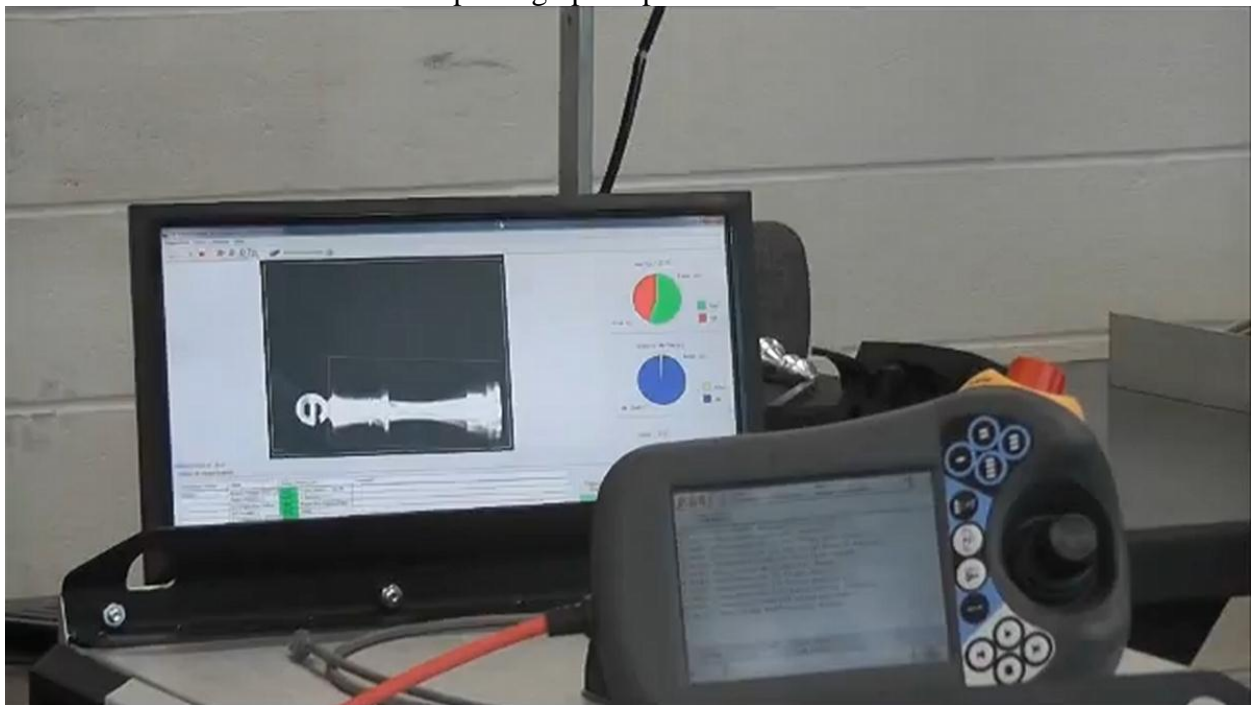
Robot picked up the pallet



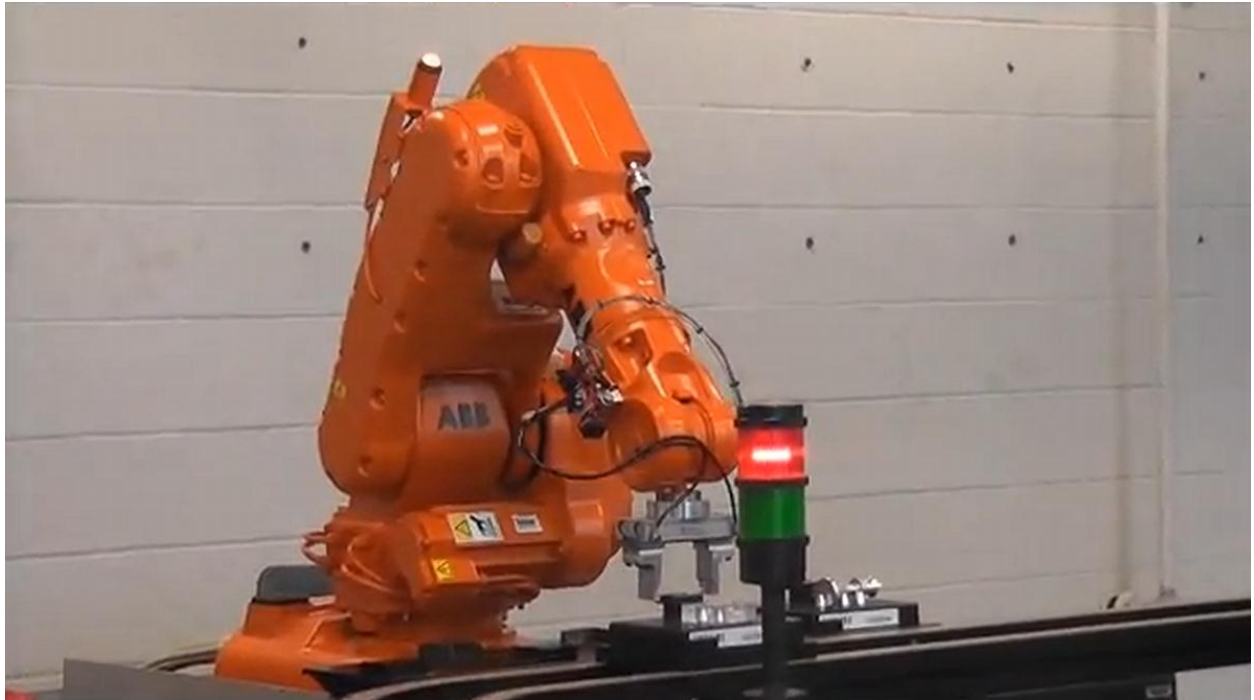
Robot picked up the part.



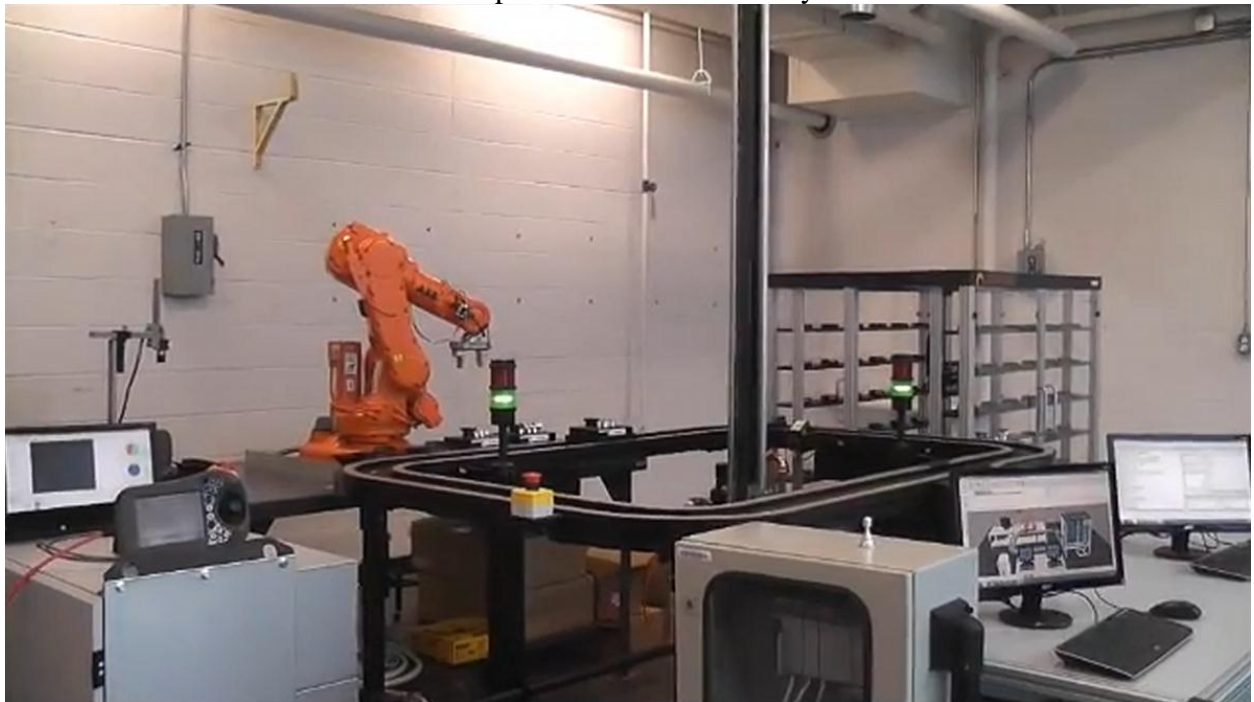
Robot is placing up the part on vision station



Vision module recognizes the part



Base part arrived for assembly.



Keep moving until the order is fulfilled.