Factory Automation – A look into the Future Developments and Integration into Industry

Connect / Protect / Explore / Inspire

Dr. Harinder Oberoi
Technical Fellow
The Boeing Company

HISTORY

Founded in 1916 in the Puget Sound region of Washington State in the U.S.

Became a leading producer of military and commercial aircraft

Completed a series of strategic mergers and acquisitions to become the World's Leading Aerospace Company

BOEING | STEARMAN | McDONNELL Aircraft Corporation | HUGHES | McDONNELL DOUGLAS | Rockwell International | BOEING

WHAT WE DO TODAY

COMMERCIAL AIRPLANES

Boeing 7-series family of airplanes leads the industry

BOEING CAPITAL CORPORATION

Financing solutions focused on customer requirements

DEFENSE, SPACE & SECURITY

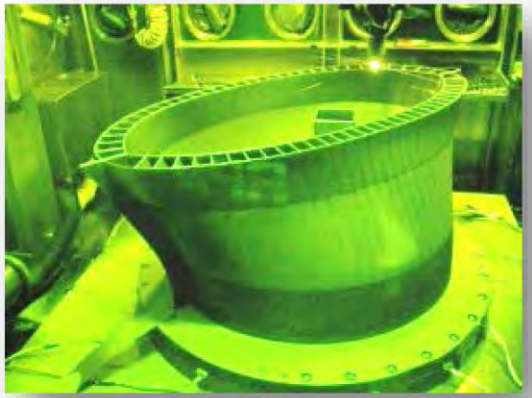
World's largest manufacturer of military aircraft and satellites and major service provider to NASA

Large-scale systems integration, networking technology and solutions provider

GLOBAL SERVICES

A dedicated services business focused on the needs of global defense, space and commercial customers

Beyond the 1st Century of Aerospace Manufacturing



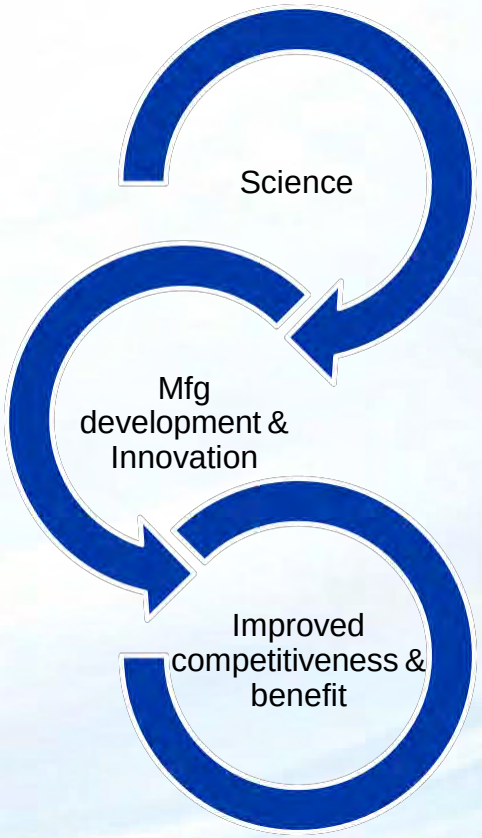
Automated Composite Fab

Additive Manufacturing

Robotic Assembly

Boeing's Goals in R&D Collaboration

- Collaboration projects must meet market environment
- Projects must meet Boeing's needs / interests
- Projects must deliver value-added / high return projects to the benefit of stakeholders
- Improves aerospace manufacturing innovation and competitiveness
- Influences funding decisions and priorities for our sponsor (METI)



Boeing & METI – Research & Development Collaboration Agreement

Agreement Signing Ceremony – January 2019

Focus Areas of Collaboration

- Electric technology, including advanced lightweight batteries and advanced motors and controllers necessary for electric propulsion systems in aircraft
- High-rate low-cost composite production technologies
- Advances in automation to improve manufacturing productivity

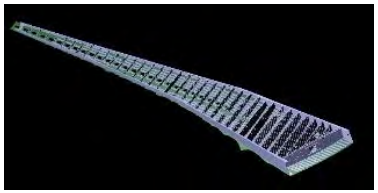
Aerospace Factory Automation Vision

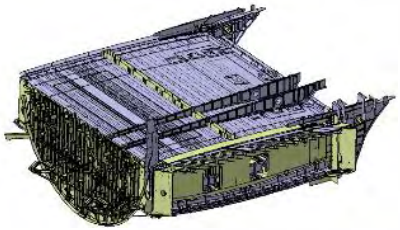
Today → → → ***Future***

Automation of Factory Production Processes

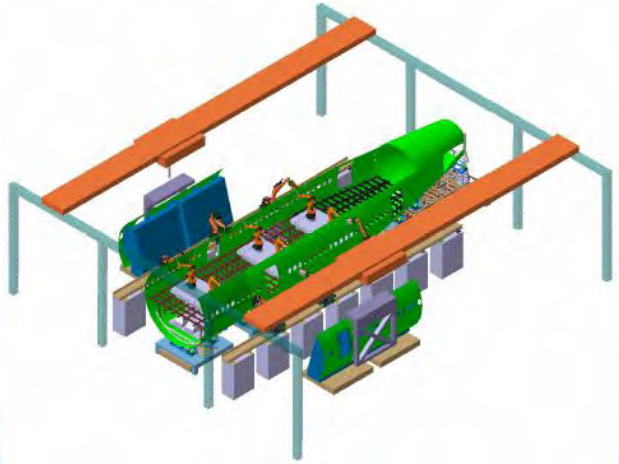
Highly Automated, AI and Humanoid Managed Factory

Robotic Sealing, Cleaning, Inspection & Painting





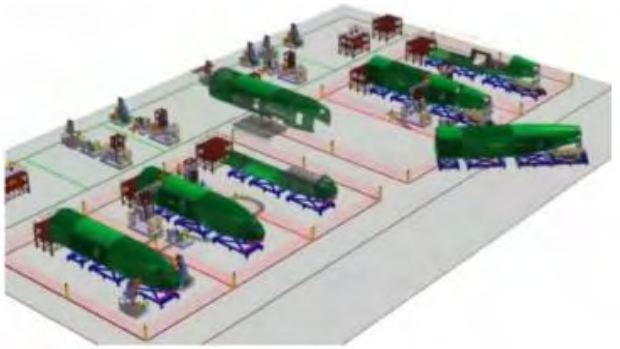
Robotic Drilling, Inspection & Fastening



Sphere of influence includes development of Innovative Automation technologies and companies

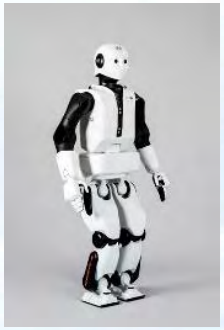
Sphere of influence includes development of Innovative Humanoid technologies and companies as solution for assisting Humans in the Manufacturing Sector

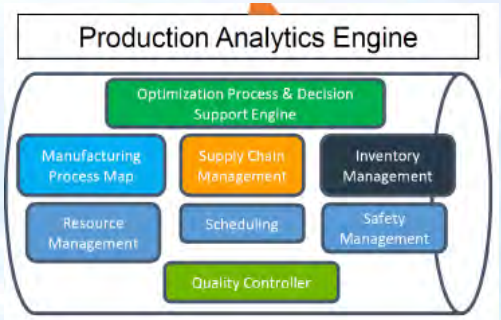
AI based highly automated factory



With the aid of advanced data analytics Humanoids will assist Humans in the management and handling all product discrepancies, off nominal production conditions and repairs on products including decision making on flyaway quality management

Advanced Musculoskeletal Robotics

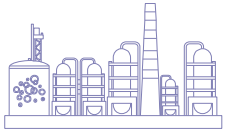




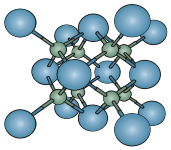
Factory Automation Technologies Development

Process Automation - Materials

Materials Science & Processing



Metallics
Metallics for Subtractive Manufacturing
Metallics for Additive Manufacturing



Composites
Thermoset Fibre Reinforced Composites
Thermoplastic Fibre Reinforced Composites
Nanocomposites
Metal Matrix Composites
Textile Composites

Historical Traditional Aerospace Products

Years of Empirical Test Data
Decades of Empirical Usage Data

Knowledge Systems

Design Allowables
Product Development Needs

Materials Strength Data
Materials Performance Data
Materials Manufacturability Data
Materials In-service Data

Analysis Reports
Build of Expert Systems
Database Learning Systems

Materials Systems Cross-Pollination
Algorithmic Manufacturability Data
Algorithmic Performance Characteristics
Algorithmic In-Service Data

Material Systems Predictive Modeling
Past & Future Material Systems Cross-Linkage
Artificially Intelligence Based Materials Selection

Next Generational Aerospace Products

Predictive Modeled Test Data
Predictive Modeled Usage Data
Acceleration of Material Systems Selection
Shortened Product into Service Introductory Times

Factory Automation Technologies Development

Process Automation – Fabrication

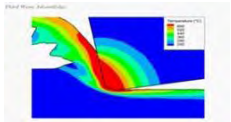
Forming & Machining Processes

Aluminium Machining
Hard Metals Machining
Composites Machining

Traditional Forming Processes
Super Plastic Forming

Components Fabrication
Wing Fabrication
Fuselage Panels Fabrication

Advanced Cutting Materials R&D
Advanced Cutting Tools R&D
Advanced System Dynamics R&D
Advanced Machine Tools R&D
Advanced Control Systems R&D



Advanced Thermal Modeling of Machining Processes
Advanced Residual Stress Modeling of Machining Processes

Image Courtesy of and approved by: Third Wave Advantage.

Technologies Advancement

Robotic Forming
Robotic Machining
Multi-Surface, Multi-Robot Simultaneous Machining

Additive Manufacturing
- *VAT Photopolymerization*
- *Material Jetting*
- *Binder Jetting*
- *Material Extrusion*
- *Powder Bed Fusion*
- *Sheet Lamination*
- *Directed Energy Deposition*

Next Generational Cutting Tools
- *3D Printed Cutting Tools*
- *Advanced Cutting Tool Materials*

Advanced Numerical Control Programming
- *Algorithmic Tool Path Construction & Processing*
- *Surface Based CAM Modeling*

Future Fabrication Equipment
- *Integrated Thermal Modeling*
- *Integrated Thermal Monitoring*
- *Integrated Residual Stress Modeling*
- *Integrated Residual Stress Monitoring*

Advancement & Sustainment of Non-Human Contact Technologies for Manufacturing

Knowledge Systems

Application of Neural Networks to
- *Forming*
- *Machining*
- *Additive Manufacturing*
- *Cutting Tools Advancement*
- *Cutting Tools Selection*
- *System Dynamics*
- *Thermal Models*
- *Residual Stress*

Assist in Semi-Autonomous AI based Process Development
- *Forming*
- *Machining*
- *Additive Manufacturing*

AI Based Forming Process Implementation & Sustaining
AI based Machining Process Implementation & Sustaining
AI based Additive Manufacturing Implementation & Sustaining

Advancement & Sustainment of AI Based Fabrication Technologies for Manufacturing

Today ***Future***

Factory Automation Technologies Development

Process Automation - Assembly

Assembly Processes

Fuselage Assembly
- *Drilling & Fastening*
- *Inspection*
- *Sealing*

Wings & Stabilizers Assembly
- *Drilling & Fastening*
- *Inspection*
- *Sealing*

Auxiliary Structures Assembly
- *Drilling & Fastening*
- *Inspection*
- *Sealing*

Automated Robotic Fuselage Assembly
- *Drilling & Fastening*
- *Inspection*
- *Sealing*

Automated Robotic Wings & Stabilizers Assembly
- *Drilling & Fastening*
- *Inspection*
- *Sealing*

Automated Robotic Auxiliary Structures Assembly
- *Drilling & Fastening*
- *Inspection*
- *Sealing*

Implementation of Autonomous Functionality for Automated Robotic Assembly Processes

Assembly Technologies Advancement

Higher Density Robotics for Assembly
- *Fuselage Assembly*
- *Wings & Stabilizer Assembly*
- *Auxiliary Structures Assembly*
- *Drilling & Fastening Advancement*
  - *High Speed Processes*
- *Sealing Automation Advancement*
  - *On-Demand Sealant Delivery Systems*
  - *In-Position Sealant Delivery Systems*
  - *Sealant Flow and Quantity Accuracy*
  - *Sealant Temperature Control*
  - *Sealant Application Quality*

Complex Surface Assembly
- *NURBS Surfaces*
- *Bezier Surfaces*
- *Parallel Computing Technologies in Controllers*

Advanced Inspection Systems
- *Non-Contact Inspection Based*
- *Closed Loop Feedback for Process Control*

Advanced Robotics
- *Miniaturization*
- *Mobility Systems*
- *Self-propelling*
- *On-board Collision Avoidance*
- *Predicative Reliability*

Autonomous Technologies Introduction
- *Robotic Assembly*
- *Robot Path Planning and Calculation*
- *Validation of Collision Avoidance*

Implementation of Artificial Intelligence Based Systems for Automated Robotic Assembly Processes

Artificially Intelligent Higher Density Robotics for Assembly
- *Fuselage Assembly*
- *Wings & Stabilizer Assembly*
- *Auxiliary Structures Assembly*
- *Drilling & Fastening Advancement*
  - *Neural Networks Development*
- *Sealing Automation Advancement*
  - *Neural Networks Development*

Artificially Intelligent Semi-Autonomous Design of Robot Assembly Systems
- *Semi-Autonomous Design of Robot Assembly Systems*
- *Semi-Autonomous Derivation of Reliability Models of Robot Assembly Systems*

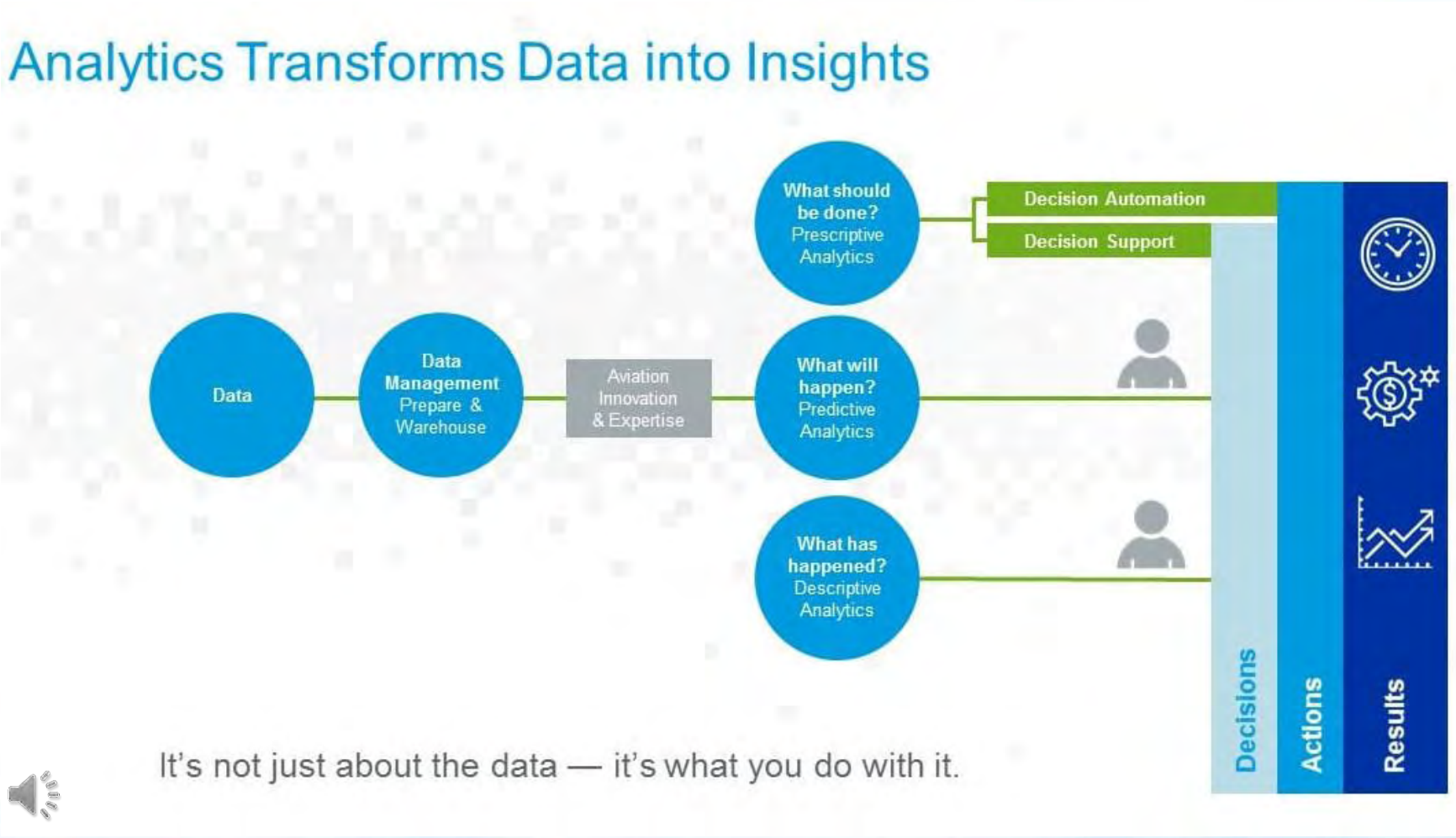
Artificially Intelligent Semi-Autonomous Build of Robot Assembly Systems
- *Semi-Autonomous Build of Robot Assembly Systems*
- *Semi-Autonomous Testing and Reliability Validation of Robot Assembly Systems*

Artificially Intelligent Autonomous Operations
- *Assembly Processes Planning and Implementation*
- *Assembly Processes Sustainment*
- *Off-Nominal Assembly Recovery Management*
- *Process and Quality Control*

Today → **Future**

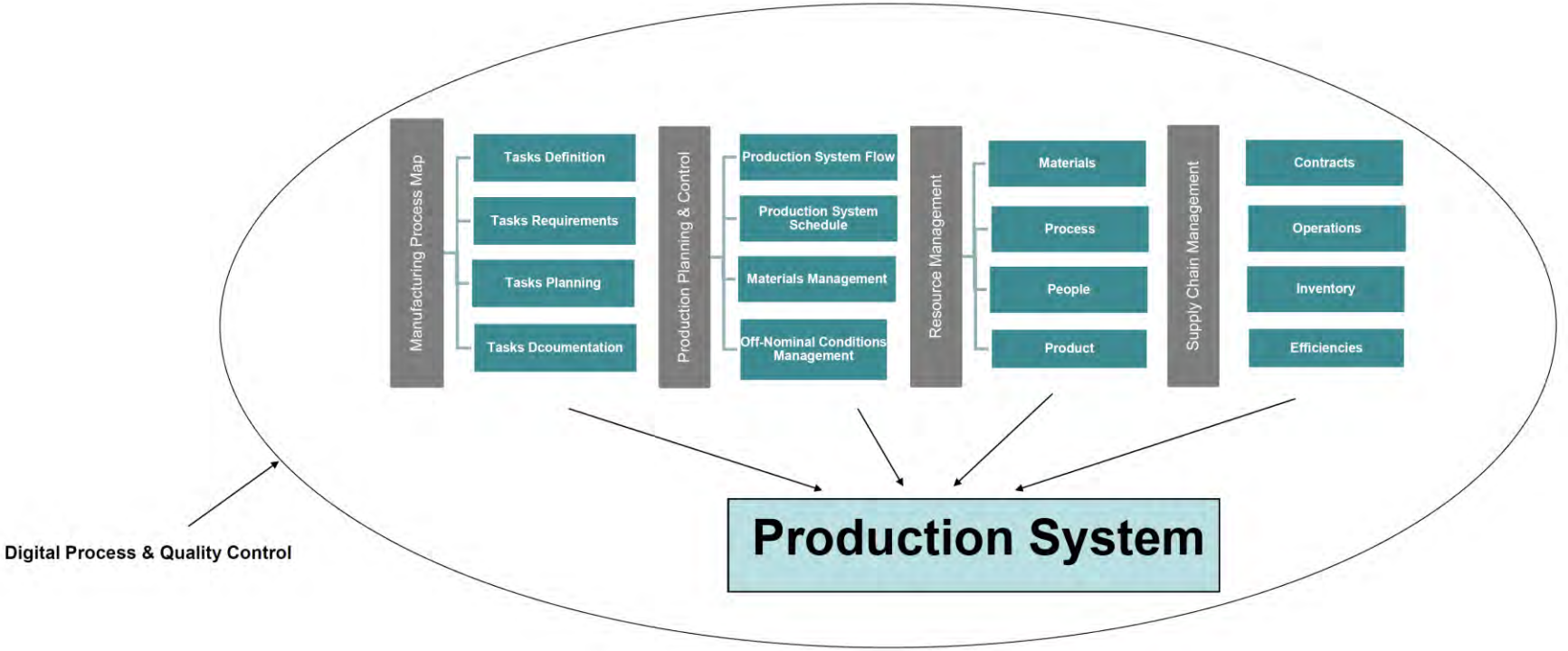
Factory Automation Technologies Development

Data Analytics Advancement



Factory Automation Technologies Development

Data Analytics Advancement



Production Analytics Advancement to focus on continued development, testing and implementation of a production analytics engine for automated production systems which includes

- *Digital manufacturing process map based on model-based engineering*
- *Production planning and control derived and managed by digital expert systems*
- *Resource management managed and maintained by digital expert systems*
- *Supply chain management with focus on efficiencies and schedules*
- *Application of Artificially Intelligent and Autonomous Data Analytics Functions*

Factory Automation Technologies Development

AI Based Production Control

- *AI based highly automated factory*
- *Material handling and delivery functions are robotic based*
- *TPM handled by AI based expert systems*
- *Production Planning and Control is AI based expert systems*
- *Factory is lights out and AI expert systems managed*

- *Further Development & Refinement of*
  - *Machine Learning*
    - *Deep Learning*
  - *Cognitive Computing*
  - *Computer Vision*
  - *Natural Language Processing*

Target

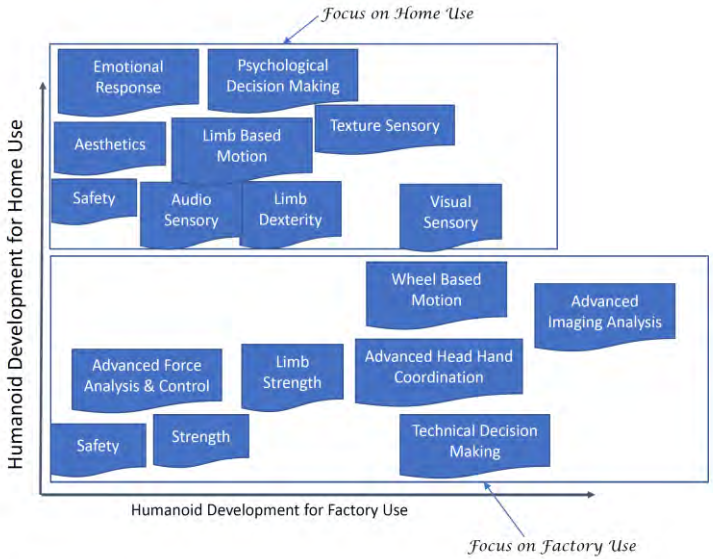
- *AI based highly automated factory managed by Humans assisted by Humanoids*
- *Humanoids assist in the management all repairs and downtimes*
- *Humanoids assist in the management and handling of all product discrepancies and repairs on products*
- *Humanoids assist in the management of all decision making for the overall Production System*

Today ***Future***

Factory Automation Technologies Development

Musculoskeletal Robotics

Needs & Requirements Development & Refinement



Technologies Advancements

Flexible Robotics Advancement
Robot Controls
- *Sensors*
  - *Proprioceptive*
  - *Extroceptive*
- *Actuators*
- *Encoders*
- *Miniaturized Control Systems*
- *Real Time Response Systems*
- *Advanced Algorithms*

Robot Frame Designs
- *Synthetic Fibre Based Frames*
- *Regeneration & Repair Capability*

Static Response Methodology
Dynamic Response Methodology
Zero Moment Point (ZMP)

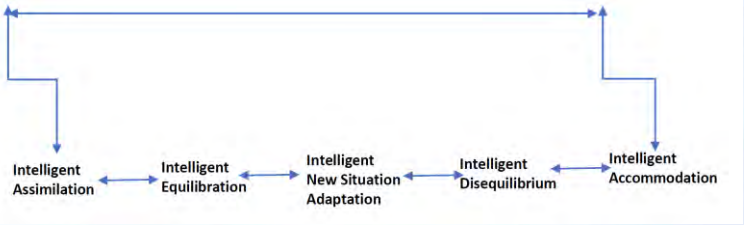
Development Psychology
- *Behavioural Decomposition*
- *Task Performance*
- *Software Architecture Development*

Vision Sciences
- *Complex Pattern Recognitions*
- *Scan Technologies and Real Time Interpretations and Analysis*

Knowledge Systems

Artificial Intelligence Systems
Advancement of Sensory Task Based Controls
Cognitive Psychology Development
- *Perception*
- *Thinking*
- *Memory*
- *Recall Dynamics*

Computational Models of Cognition



Navigation & Gait Planning
Compliant Control of Whole- Body Multi-Contact Behaviours
Advanced Methods for Accurate and Robust Acquisitions and Analysis
Advanced Mobile Position and Trajectory Controls

Today → **Future**

Factory Automation Technologies Development

Integration into Industry

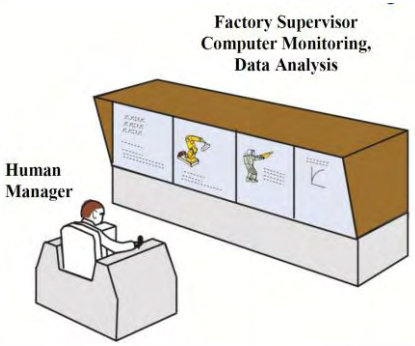
Automated Factory

Flexible Robotics Systems
Lighter, Smaller Robotic Systems
Higher Density Robotic Systems

Factory Planning
- *Modularity of Automated Equipment Operations*
- *Modularity of Automated Equipment Maintenance*
- *Mobility of Utility Services for Automation Equipment*
- *Kitting of Tools, Services for Automated Equipment*

Advanced Production Planning & Control with Off-Nominal Conditions Management

Autonomous Automated Factory

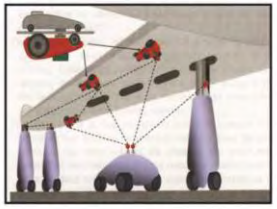


Introduction of Automated Guided Vehicle (AGV) Based Automation
Factory Spatial Development
Factory Layout Development
AGV Traffic Management
Hi-speed Data Transmission Networks

AGV based Materials & Tool Management
Autonomous Process and Quality Control
Autonomous Production Planning & Control

Modular Factory Layout to accommodate
- *Changes in Production Plans*
- *Changes in Product Lifecycle*
- *New Product Introduction*

AI Based Automated Factory



Future Aircraft Manufacturing System Using Paired Mobile Robots: No Scaffold, Jigs, Fixtures, or Gantry Are used

Introduction of Humanoids Based Automation
Advanced Factory Control Visions Systems
Maintenance and Repair areas to be setup for Humanoids to work on automation equipment
Sound and vision based alert systems for off-nominal conditions

Cloud based Data Transmission and Management
AI based libraries setup for Humanoid Access
Technology Test areas setup for access by Humanoids
Planning for uninterrupted and resolution based utility services
Clear and Concise Emergency Shutdown policies and procedures

Today ***Future***