Research Advances in Manufacturing with Service-Oriented e-Work and Production

Shimon Y. Nof
PRISM Center, and School of Industrial Engineering, Purdue University

PRISM Center
Production, Robotics, and Integration
Software for Manufacturing and Management

“Knowledge through information; Wisdom through collaboration”
I slept and dreamt that life was joy.
I awoke and saw that life was service.
I acted and behold, service was joy.

Rabindranath Tagore

- Software as service
- Upgrades
- Repairs; maintenance
- Design and innovation services
- Reverse logistics (sustainability)
- Service engineering

Can intelligent mfg. exist without them?
Stages of advancing supply & mfg. services – enabled by better information exchange and knowledge sharing (*internal and external*)

a. Push Production

b. Pull Production

c. Customer - Centric Production

d. Customer - Driven Production

1/2. Service Orientation
Intelligent mfg. \(\Rightarrow\) Services-oriented mfg.

**Level of Automation and Intelligence through Computerized Knowledge**

- Etc.
- Bio-inspired
- Collaborative Mfg
- Networked + Sensored
- Virtual Mfg
- iMaterials
- Clix (Computer Integrated ...)
- CAx (Computer Aided ...)
- Islands of automation
- Automated
- Mechanized
- Etc.

**Human and Social Knowledge**

- Craft \(\rightarrow\) Mfg. \(\rightarrow\) iMfg

**PRODUCT** {Physical; Digital; Combination}

Examples: {Table; Software; Car}

**SERVICE** {Mfg. related [Service for Mfg.; Service as Product]; [Other Services (?)]}

Examples: {[Machine repair; Logistics, Entertainment]; [Cleaning, Financial, Healthcare]}

2/2. Internal and external embedded software services
Increasing role of knowledge services embedded in intelligent manufacturing

**Manufacture** = (1) Create + (2) Innovate + (3) Design + (4) Market + (5) Supply (including also procure, plan, handle materials, etc.) + (6) Fabricate + (7) Build + (8) Assemble + (9) Test + (10) Inspect + (11) Repair + (12) Package + (13) Ship and Distribute + (14) Install + (15) Maintain, Clean + (16) Recycle

**Manage:** (a) Human Resources + (b) Finance + (c) Transport + (d) Facilities and Projects + (e) Accounting + (f) Utilities + (g) Information + (h) Legal and Community Relations + (i) Inspiration, Innovation, Beauty and Spirit of Manufacturing.
Work $\rightarrow$ e-Work $\rightarrow$ c-Work as services become inherent to manufacturing within an enterprise

Knowledge Services:
- Information,
- Control,
- Interactions,
- Decisions

Major service tools of c-Work

Error elimination; Faster; Higher integration complexity
Services become inherent to mfg. throughout the supply network’s interactions
Challenges in Collaborative e-Work and e-Service

Proctor et al. (2011); Singh & Khamba (2011); PPC (2012); Nof et al. (2013)

• The principles of the work system have changed.
• Advancing technology increases productivity yet challenges and complexities also increase:
  1. Optimize operations despite information and task overloads;
  2. work complexity;
  3. Higher inter-dependence;
  4. Integrity and trust;
  5. Need for coordination, cooperation, and synchronization;
  6. Communication challenges and failures;
  7. Mismatch obstacles -- inconsistent versions, cultural differences;
  8. Repeated training requirements and associated costs.

Knowledge-based e-Services are viewed as major contributors for addressing these challenges.
The Telecommunication-Based Factory (TBF)

Fleury & Fleury (2007); Fleury, Gregory, Bennett (2007)

- Fundamental “Factory of-the-Future” models

- Integrators (System providers)
  - Specifies the system’s requirements
  - Integrates solutions, delivers the system
  - Provides technological solutions

- Operators
  - Interact with end markets
  - Provides technological solutions

- Solution Developers
  - Specify the technical requisites
  - Specifies product’s characteristics

- Technology Specialists
  - Develops process
  - Delivers products

- Market/Customer

- Manufacturing Contractors
  - Delivers products

- Logistics Operators
  - Interact with end markets

- Manufacturing Contractors
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- Logistics Operators
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Collaborative Control Theory (CCT) principles, and CSS, Collaboration Support Systems

1. **CRP**: Collaboration Requirement Planning
2. **PARK**: Parallelism + KISS: “Keep It Simple, cyber System!”
3. **CEDP**: Conflict & Error Detection and Prognostics / Prevention
4. **CFT**: Collaborative Fault-tolerance by Teaming
5. **JLR**: Join/Leave/Remain in a collaborative network
6. **LOCC**: Lines Of emergent Command and Collaboration

- HUBs (“Internet on steroids”) enable CI, Collaborative Intelligence focused on improving human ability to collaborate effectively

**CCT + CSS = Collaboratorium Initiative for CI [Purdue, 2008]**

[Diagram: 3D representation with axes labeled Access + Interaction Science e.g., human visualization; Domain Knowledge + Content and Tools e.g., NanoHub.org]
e-Work agents models: Holonic Mfg. System (HMS) bio-inspired architecture  

- Workflow model repository
- Resource activity model repository
- HMS Designer
- Administrator
- Order manager
- Product manager
- Resource manager
- Features:
  1. Autonomy
  2. Responsiveness
  3. Redundancy
  4. Distributedness
  5. Learning
  6. Efficiency
  7. Less conflicts / errors

*Hsieh & Chiang; Brennan, Gruver, Hall (2011), Valquenaers (2013)*
e-Work middleware: The Service Oriented Architecture (SOA)

SOA activities:
1. Collaborative automation units
2. System of systems by networking
3. Operating to achieve goals

Example: Oracle® Workflow Architecture (Sayed & Ameen, 2011)

- Role of data mining and discovery to
  - Maintain timely, relevant, proactive knowledge;
  - Online analytics;
  - Predictive decision support
Comparing two logic designs for TAPs

Benefits of demand and capacity sharing protocols

(Seok et al. 2012)

Comparing TAP to Coordination protocol

(Ko & Nof, 2012)
1. Manufacturing “big picture” means service orientation: For effective, quality delivery of manufactured products, and competitiveness

2. Major opportunities for innovation through new and better service models for knowledge-based, collaborative lifecycle management of manufacturing

3. Need to design competitive agents, protocols, and models (architectures) for better collaboration services to overcome the “eight challenges.”

4. Three challenging examples for emerging service orientation:
   a. Collaborative production lines (CPL; ALB-TS*)
   b. Collaborative telerobotics (CTR*)
   c. Collaborative telepresence (HUB-CI*)
Facility sensor networks (FSN) emerging in mfg., hospitals, airports, rail, ...

Wireless Sensor Network

- Wireless node deployment
- Mesh networking

Server

- Wireless
- Base station
- Data collection
- Data processing
- Web service

Client

- TCP/IP
- User interface
- Presentation
- Task administration protocols

• Fundamental models of device collaboration services

Jeong & Nof, 2009; Jeong et al., 2013
Collaborative Production Line Control Protocol - CPLCP

- Tissue Converting Line Control with CPLCP
- Highly adaptive and anticipatory, by collaboration among different line(s) components to overcome failures
- Maintain sustainable throughput while keeping WIP low
- Better mfg. performance and efficiency for economic, social, and environmental sustainability

CPLCP + S-DSP

- Fundamental protocols for resource allocation
- Fundamental protocols for error and conflict detection, resolution, elimination

Levalle et al. (2012)
HUB-CI model for collaborative telerobotics (CTR): Collaborative Lifecycle Management application

(Zhong & Nof, 2013)
Conclusions and Challenges

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nof@purdue.edu
The HUB-CI model for collaborative telepresence

- Emerging global networks (hubs/clouds) to trade/adapt/engage/learn diverse ideas through collaboration with sustainability

...challenges:
- Cross-culture capabilities?
- Multi-cultural interaction and infrastructures?
- Challenged web-based applications?
- Asynchronous multimedia?
v-Design with CAD, CAE, CAVE, Augmented Reality

- Fundamental protocols for error and conflict detection, resolution, elimination
TestLAN e-Services inside assembly-&-test facilities, and across supply networks

- Fundamental protocols for resource allocation

*Nof (2003; 2012)*
Independent, autonomous service-oriented devices

• Fundamental models of device collaboration services

Need external support? Need reconfiguration?

Distributed Management Service

Test Event

Business Level

Factory Floor

SERVICES:
- Sync. Service Activities
- Read-Write I/O
- Update Control Model

Initial Setup & Configuration

Evolve System

Receive Event

Lateral Collaboration

Service-Oriented Device

Lateral Collaboration
Collaborative e-Work

Integration & Collaboration

Distributed Decision Support

Active Middleware

Agents

Protocols

Theory & Models

Workflow

Collaboration & Interaction Models

HCI

CIM

Extended Enterprise

Middleware Technology

Distributed Knowledge System

Knowledge-Based System

Grid Computing

Decision Models

Distributed Control Systems

Collaborative Problem-Solving
Intelligent manufacturing can often be viewed as collaborative e-Work and e-Mfg

- Manual search
- Electronic assembly
- Database search
- Micro-electronics
- Search engine
- Nano-electronics

Error elimination; faster; higher integration complexity
Examples of **e-Work with e-Service** (not only Internet), and impacts on e-Mfg. and e-Logistics

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<thead>
<tr>
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<tbody>
<tr>
<td><strong>Distributed Computing, Information Exchanges, and Web Services</strong></td>
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<td>1. Teleconference</td>
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<td>2. EDI (data interchange)</td>
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<td>3. EFT (fund transfer)</td>
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<td>4. Virtual reality for training</td>
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<td>6. GPS-based monitoring</td>
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<td><strong>Collaborative CNC/Robotics/Human-Robot Teams</strong></td>
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<td>1. Tele-robotic facility repair</td>
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<td>2. Networked CNC, test, inspection</td>
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<td>3. Tele-assembly in clean room</td>
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<td>4. Diagnostics by sensor web</td>
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<td>5. Robotic laser drilling</td>
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<td>6. Robotic load/unload devices</td>
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Intelligent Manufacturing with e-Services

The ability to transform activities, processes, materials and products to being knowledge-based and intelligence-based implies --

Transfer of human knowledge and intelligence to them, through e-Services:
Providing services via electronic communication networks
What do we get out of this presentation?
What’s new?

1. For us, manufacturing aficionados, what does “service oriented” mean?
2. How are e-Work and e-Mfg. related to “service orientation”?
3. How has this relation evolved, and where is it going?
4. (How) can we benefit from it?
5. What do we need to do about it? (Challenges)