History and Perspective of Simulation in Manufacturing

Leon.mcginnis@gatech.edu

Oliver.rose@unibw.de

Agenda

- Quick review of the content of the paper
- Short synthesis of our observations/conclusions
- Suggested "grand challenges" for manufacturing simulation
- Discussion

Introduction & Warnings

- This is a limited view on simulation in the manufacturing area, based on:
  - High level view of 60 years of published research in this area
  - Interviews with vendors & large company users
  - Our combined 64 years of experience in this field
- Our perspective is strictly **logistics**, i.e., the flow of material within a factory including all issues of design, planning and control that impact operational flow

About Manufacturing

- Material **flows** through **processes**, which are executed using **resources**, to change the material to a higher value state.
- Simulation is used to create a "**virtual factory**"
- We can **experiment** at low cost and no risk
- Requires **fidelity** between real and virtual factory plus reasonable amount of **time** and **cost** to perform the modeling and the experiments
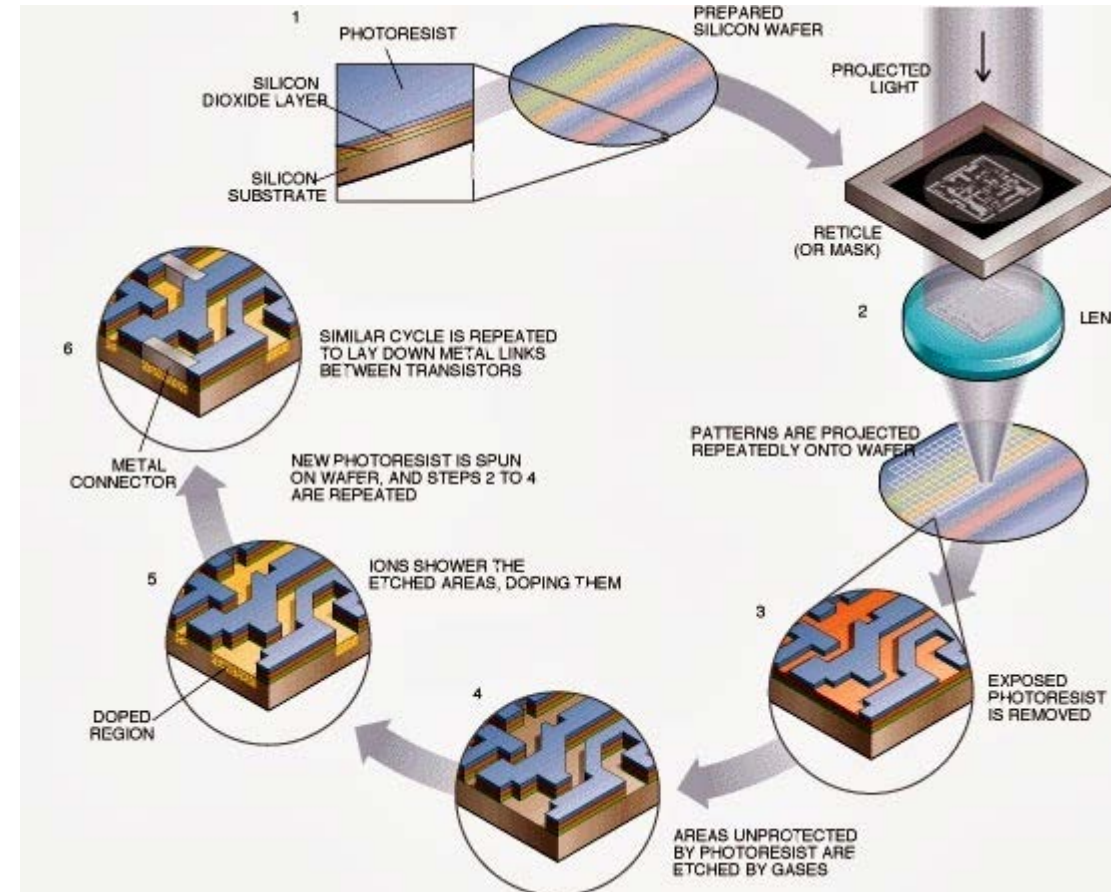
Questions Answered Using Simulation

- About manufacturing systems which exist, either concretely or intentionally

- What amounts of which resources are needed?
  - production materials, processing tools, fixtures, storage space, etc.

- How should the flow be controlled?
  - time-bucket oriented plans (intentions) or operational decisions about release, sequencing, assignment, routing or setup.

Design decisions
versus
Operational control decisions

Manufacturing Simulation Publications

- Subset of simulation application publications in industrial engineering (IE), management science (MS), and operations research (OR)

- The beginning
  - Jackson (1957): digital computation for job shop scheduling
  - Harling (1958): technical issues and random number generation
  - Conway, Johnson, and Maxwell (1958): job shop simulator
  - Conway, Johnson, and Maxwell (1959): practical issues of the simulator
  - Kuratani and Nelson (1960): another job shop simulator plus experiments

- Due to lack of computer power, very simple models were used

- Early papers discuss fidelity limitations, but outline huge potential plus the complaint about appropriate tools (sounds familiar …)

Arrival process

Queue

Service process

Queue

Departure process
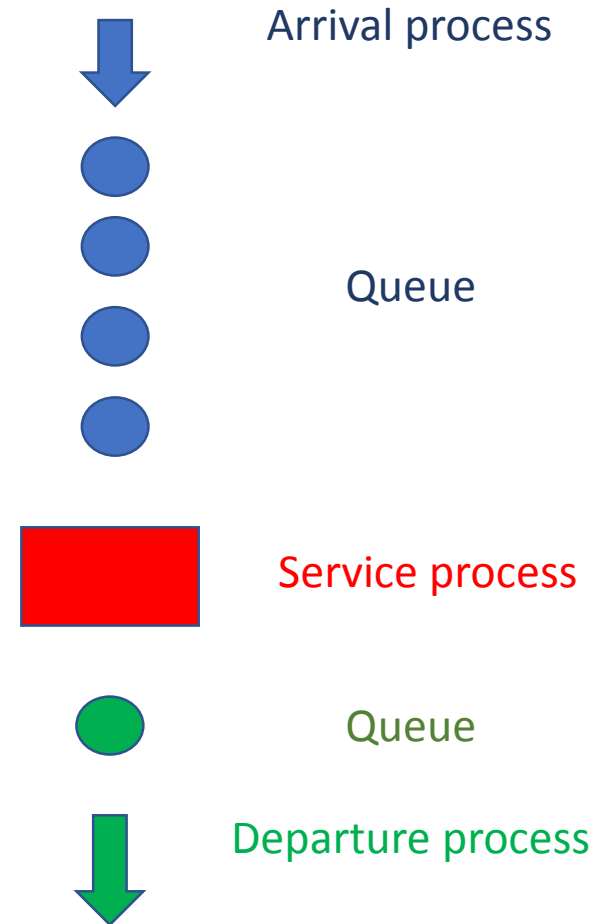
No separation of plant and control in early simulation models

Manufacturing Simulation Publications

- Society for Modeling and Simulation International
  - First issue of _Simulation_ was published in September, **1963**
  - First manufacturing paper was Reitman (**1967**) about a GPSS model of a semiconductor factory (!!!)
  - Sims (**1981**) describes a GPSS serial production line model
  - From 1963 to 1983, these were the only papers about manufacturing in this journal
  - From **1984 to 2004**, the interest in manufacturing simulation increased but remained on a conceptual level, often discussing the cost of "hand-crafting" a simulation model while showing the potential use for decision making
  - From **2005 to 2016**, we see a growing interest in using simulation for manufacturing system design.

Manufacturing Simulation Publications

- Other journals

Decade	IJPR	All Jnls
1/60 - 12/69	9	90
1/70 - 12/79	26	213
1/80 - 12/89	112	615
1/90 - 12/99	284	1994
1/00 - 12/09	412	14244
1/10 - 12/15	796	26872

Manufacturing Simulation Publications

- Winter Simulation Conference
  - Through 2016, 1448 papers mention manufacturing and simulation
  - The growth rate is about 150 papers per decade
  - There are 12 papers in the archive with more than 1000 downloads, 5 of which address supply chains
  - There are 12 papers with more than 20 citations (#1 is Barton (1998) about response surface modeling)
  - Only for 5 of the 21 top ranking papers manufacturing simulation is the main focus (vs, say manufacturing supply chain or a particular methodology)

Manufacturing Simulation Publications

- Winter Simulation Conference
  - Two main areas of application: automotive (70+) and semiconductor (340+) manufacturing
  - Automotive papers: more design related simulation
  - Semiconductor papers: more material flow control related simulation
  - Although large part of the papers claim to be „methodological", there don't seem to be „breakthrough" change in practice and research over the years

Large companies where design costs and operational efficiency are critical to competitiveness; can't not do simulation!

Impressions about the Literature

- Most papers have a very specific focus, either particular application or particular simulatin approach (agents, e.g.)

- Hard to extract general engineering principles

- There is no research that builds a theoretical foundation for simulation in the manufacturing domain

- Consequence: no textbooks about manufacturing simulation, manufacturing is only used as example or use case in more general textbooks

Manufacturing Simulation Practice

- Tools of the trade
  - Our field depends on the availability of modeling and simulation tools
  - Started with the work of Alan Pritsker (GASP/SLAM)

- Automotive factory design has simple flows
  - „out of the box" simulation tools have been adequate
  - Future applications require much more complex flow management

- Semiconductor flows are perhaps the most complex in manufacturing
  - „out of the box" simulation tools inadequate
  - High degree of customization to accommodate operational flow control logic

Manufacturing Simulation Practice

- Major concerns
    - Contemporary „drag n drop" approach doesn't scale
    - Lack of innovation in the modeling paradigm
    - Lack of interest in simulation by recent grads/new hires
    - Aging workforce of „simulation experts"
    - Integration of manufacturing simulation with new concepts, like „smart factory", „digital thread", „Industrie 4.0"

Manufacturing Simulation Practice

- Inhibiting factors for the application of simulation in manufacturing
  - **Organization**: „Math approach", depends on abstract models
  - **Sceptics** on all levels of the company hierarchy (mainly due to bad experiences); consequence: models become more complex than need and thus more expensive
  - **Modeling competence**: Requires a skilled local staff or expensive external consultants
    - Not learned in school
    - Requires mentoring and permanent practice
  - Contemporary simulation tools are easy to use for trivial models but not for realistic industry use cases, in most cases **deep coding skills** are required in the underlying implementation language

Manufacturing Simulation Practice

- Inhibiting factors for the application of simulation in manufacturing
  - **Data**: even after 50 years of simulation, data problems are common
  - High-quality **data collection is expensive**; if not convinced about the usefulness of a simulation project, why spend money for that?
  - Data with the highest performance impact (**rare catastrophic events** like breakdowns), have the smallest sample size
  - **Return on investment**: despite large number of studies, trustworthy estimates are not available
  - Hard to make a **business case** for simulation if it just an option and not a must

Conclusions: Difficulty

- Even after 60 years, finding suitable compromise between fidelity, time, and cost of manufacturing simulation modeling remains a challenge
- The claim that simulation modeling is straightforward and that we just need slightly better tools is not very helpful
- Building abstract models will remain an expert business with an increasing requirement of deep IT knowledge because current and future manufacturing systems contain too much IT-driven components
- In addition, the modeler requires a deep understanding of experimental design and statistics
- The ability to understand complex systems on an abstract level will prevail and it will be independent from the development of new tools

Conclusions: Tools

- Simulation tool vendors quickly pick up new trends and methods from software and computer engineering, but do these address the real needs?

- Manufacturing simulation models are still largely „hand crafted"

- There is no computer support to decide about model boundaries and about the level of detail of model components

- Other domains benefit from a common (standard) language for the description of the design and the operation of their systems, but this has not happened for manufacturing systems

Conclusions: Business Case

- We must find a more compelling „value proposition" for simulation when it is not absolutely required for risk mitigation, otherwise the application of simulation will not achieve its full potential in manufacturing

- When industry is worried about the cost of educating simulation experts, academia has to offer more attractive simulation curricula at universities to attract young engineering students

    - Perhaps what constitutes acceptable simulation research needs to incorporate innovation in the application domain as well as in the methodology domain?

    - And maybe industry needs better career paths?

Challenges and Opportunities

- Landscape for manufacturing simulation is rapidly changing
  - Industry 4.0, internet of things, cyber physical systems, cloud computing, etc. etc. etc.
  - Tool vendor fascination with virtual reality and even more „drag&drop" libraries
  - Tightly coupled systems of manufacturing facilities require greater capability for modeling process and flow control policies and algorithms
  - Scale and complexity of contemporary systems may make the „single modeling expert" an obsolete approach
  - New systems create tidal waves of data, but is it the right data?
  - Who educates the necessary data analytics experts? Modeling experts?

Grand Challenges

- Reference models (and ontologies) for important manufacturing domains – we need a common system specification language
  - Libraries of standard manufacturing system components
- New generation of simulation tools – plant/control separation, embeddable decision-making algorithms
- Automation for "standard" simulations (cf, FEA/CFD in mechanical or aerospace design, circuit simulation in digital device design)
- Innovative and exciting simulation curricula, to attract and prepare the next generation of manufacturing simulation experts
- Value proposition for manufacturing simulation must be more than "risk of failure is too great without it"