

# FSM Research: Challenges, Opportunities & Current Thrusts in Wafer Manufacturing



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# Fab Dynamics

Factory is driven by Cost, Productivity, and Speed:

- ☞ Reduce factory capital and operating costs per function
- ☞ Faster delivery of new and volume products to the end customer
- ☞ Efficient high volume production, high reliability, & high equipment reuse
- ☞ Enable rapid process technology shrinks and wafer size changes

# Why do research in High Vol Mfg?

- Moore's Law enabling significant technology development
- Manufacturing methods, techniques and innovation must keep pace with our technology roadmap
- Leveraging Universities for Manufacturing research allows us to explore fundamental and innovative concepts and theories

# Developing Manufacturing Research Roadmap

(1) A VISION OF THE FUTURE

(3) Difficult Challenges  
(or gaps) that must be overcome

(4) Potential Solutions  
that must developed

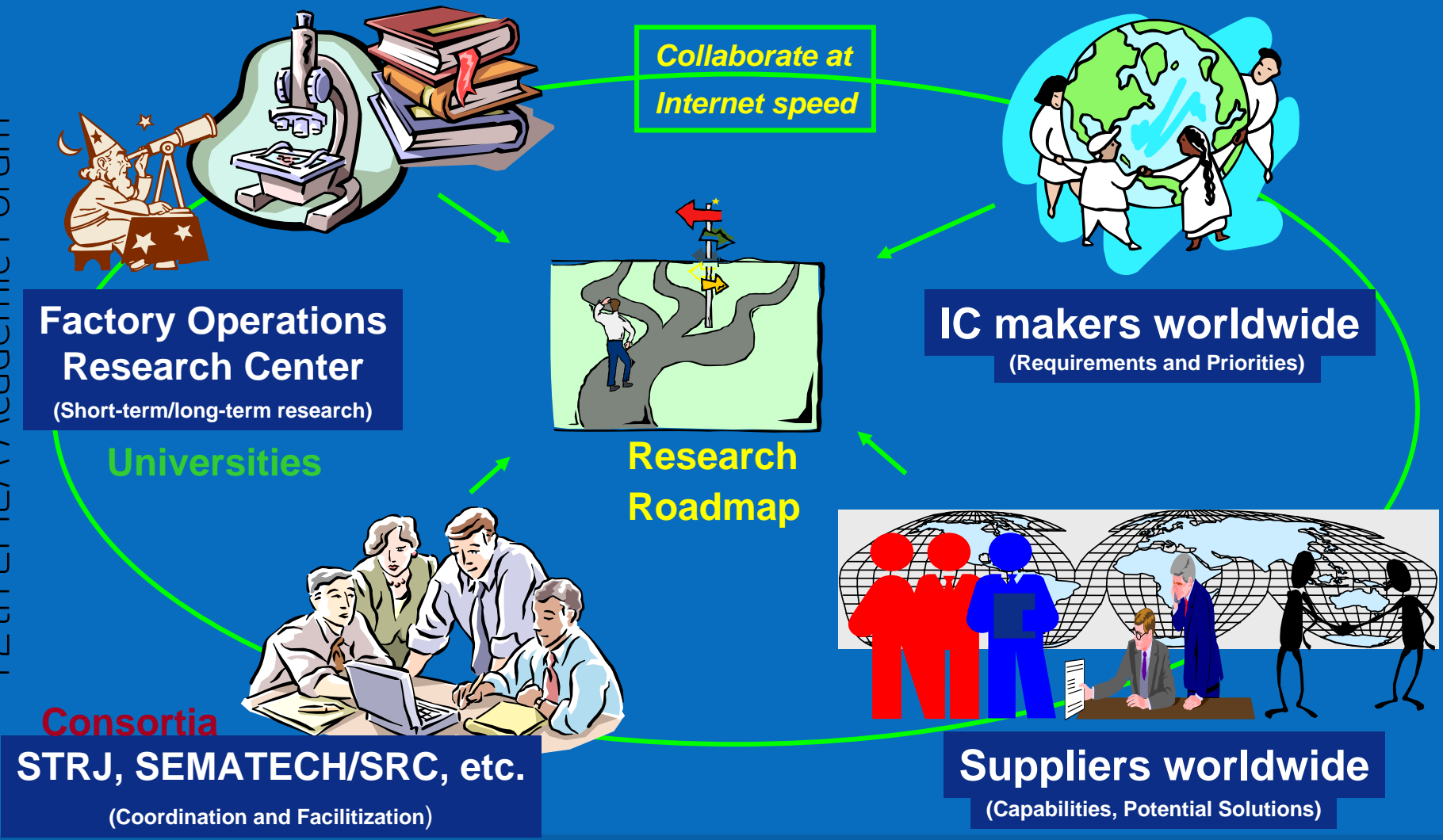
(2) Technology  
and  
Business  
Requirements

(6) Cross-cut domains  
its relationships must be understood & its potential solutions made available

(5) Deployment date  
to which solutions and products must be synchronized

# Research collaboration models

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**A single engagement model does not fit all scenarios**



# Research Methods

Seeking  
Improvement  
with a new  
Technology

Applying  
a known  
technology to  
a problem

## 1) Engage members of the Research community to identify

- 
- Technologies people using outside of Intel that we should be exploring?
- Current state of research on the technologies
- Informed estimates about the future of the technologies

## 2) Engage members of the Intel HVM organization to identify

- Targets of opportunity for application of the technologies
  - it may address a widely recognized problem
  - it may dramatically impact something not considered to be a problem

## 3) Engage members of the Intel HVM organization to identify

- The target problem, boundary conditions, assumptions, timing, etc

## 4) Engage members of the Research community to identify

- The world-class experts on the problem you have specified
- The appropriate research arrangement with the experts

# ITRS FI 15 year roadmap

International Technology Roadmap for Semiconductor (ITRS) Factory Integration (FI) evaluates industry's difficult challenges and technology requirements to formulate potential solutions to meet these needs

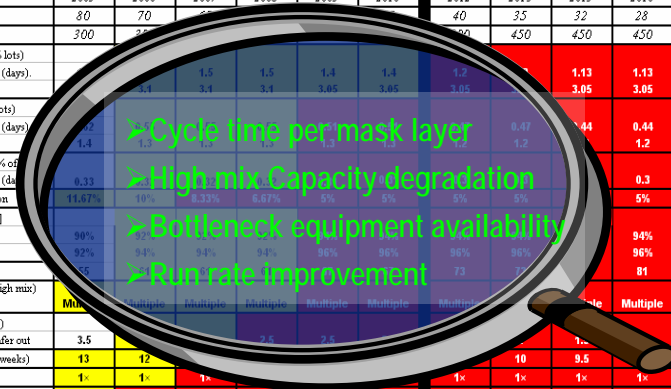


## Develop FI challenges (world wide participation)

Difficult Challenges 2007 nm	Summary Of Issues
Responding to rapidly changing, complex business requirements	Many new and co-existing business models including IDM, Foundry, Fabless, Joint Ventures, Collaborations, etc. Outsourcing, etc need to be considered in the Factory Integration
Increased expectations by customers for faster delivery of new and volume products	Need for improved integration of the entire product design and manufacturing process
Faster design -> prototype and pilot -> volume production	Enhanced customer visibility into outsourced production operations
Managing ever increasing factory complexity	Increasing dedication of assets and equipment causing manufacturing inefficiencies Challenges introduced with sharing of mask sets Difficulty in maintaining the historical 0.1% transistor shrink per year for die size and cost efficiency
	Quickly and effectively integrating rapid changes in process technologies Managing carriers with multiple lots, wafers with multiple products, or multiple package form factors Comprehending increased purity requirements for process and materials Need to run aluminum and copper back-end in the same factory Increasing number of processing steps coupled with process and product complexity Need to concurrently manage new and legacy software and systems with increasingly high interdependencies Explosive growth of data collection/analysis requirements driven by process and modeling needs Increased requirements for high mix factories. Examples are complex process control as frequent recipe creation and changes at process tools and frequent quality control due to small lot sizes

## Develop FI technology requirement tables based on challenges

Year of Production	2005	2006	2007	2008	2009	2010	2012	2013	2015	2016	2018	2019	2020
Technology Node	90	70	55	45	35	30	20	15	10	7	5	4	3
Wafer Diameter (mm)	300	300	300	300	300	300	450	450	450	450	450	450	450
Non-hot lot (average of 94% lots)										1.13	1.13	1.05	1.05
Cycle time per mask layer (days)			1.5	1.5	1.4	1.4	1.2	1.2	1.1	1.1	1.05	1.05	1.05
X-Factor [1]			3.1	3.1	3.05	3.05	3.05	3.05	3.05	3.05	3	3	3
Hot lot (average top 5% of lots)										0.44	0.44	0.39	0.39
Cycle time per mask layer (days)			1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.1	1.1	1.1
X-Factor [1]			1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.1	1.1	1.1
Super hot lot (average top 1% of lots)										0.3	0.3	0.3	0.3
Cycle time per mask layer (days)			0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
High-mix capacity degradation			11.87%	11%	8.33%	8.87%	5%	5%	5%	5%	5%	5%	5%
Bottleneck equipment [2] [3]													
Utilization			90%	92%	94%	94%	96%	96%	96%	96%	94%	94%	94%
Availability			92%	94%	94%	94%	96%	96%	96%	96%	96%	96%	96%
Wafer layers/day/head count			56	56	56	56	73	73	73	73	81	89	89
Number of lots per carrier (high mix) [4]			Multiple	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple
Facilities cycle time (months)													
1st tool to 1st full loop wafer out			3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Node -to-node change-over (weeks)			13	12	12	12	10	10	9.5	9	9	9	9
Floor space effectiveness			1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x
Average number of wafers between reticle changes			40	35	30	25	20	20	20	15	15	13	13



> Cycle time per mask layer  
> High-mix Capacity degradation  
> Bottleneck equipment availability  
> Run-rate improvement

Focus on reduction in cost per function by 30% per year [historic norms] & productivity Improvement  
Focus on delivering new/ compelling IC devices that continue our growth

## Provide direction for the semiconductor

Drive direction for industry research, pre-competitive standards and industry enabling capabilities

Learn from each other (ex. High Mix production, requirements)

Influence Supplier Roadmap (common industry requirements, drive potential solutions, set time table for solutions)

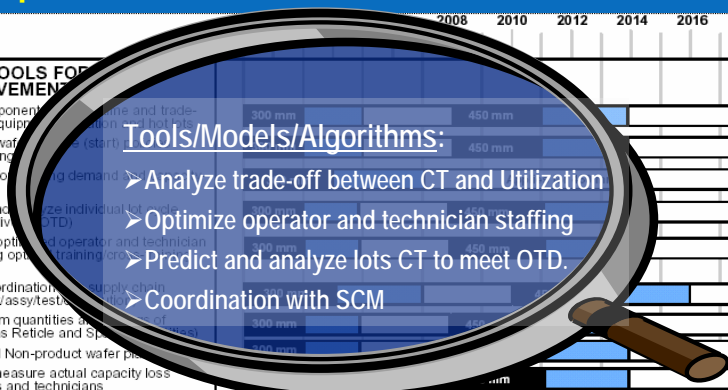
Influence other IC Maker Direction (reduce re-invention, pool resources, increase reuse for cost reduction (standards))

Understand our competitive position in the industry and where we need to drive changes

Show Industry Leadership & Recruit students

## Develop FI potential solution tables based on technology requirements

DECISION SUPPORT TOOLS FOR OPERATIONAL IMPROVEMENT	2008	2010	2012	2014	2016
Tools for understanding component trade-off between cycle time and equipment utilization					
Tools/algorithms/models for wafer based bottleneck monitoring					
Tools/algorithms/models for demand integration					
Tools to accurately predict and optimize On-Time-Delivery (OTD)					
Tools/algorithms/models for operator and technician staffing levels and developing optimization plans					
Integrated techniques for coordination and management efforts (fab/sort/assy/test)					
Tools for determining optimum quantities and operations resources (such as Reticle and Spacers)					
Tools for determining optimal Non-product wafer placement					
Tools/algorithms/models to measure actual capacity loss components due to operators and technicians					



Tools/Models/Algorithms:  
> Analyze trade-off between CT and Utilization  
> Optimize operator and technician staffing  
> Predict and analyze lots CT to meet OTD.  
> Coordination with SCM

Source: International Technology Roadmap for Semiconductors

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# Some Projected Attributes of a 300mm $\leq$ 45nm Fab

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Data standards and Systems for Rapid Mask Set Creation



Equipment & Systems designed for High Mix operation

**Very Fast Cycle time Fabs for Hot & Normal lots**

Wafer Data Standard For Packaging



Aggressive NPW Reduction & Efficient Spares Mgmt

Full Wafer Level Tracking & Recipe/Parameter Changes

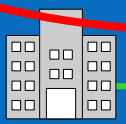
Ubiquitous APC; Rapid Process Matching & New Product Qualification

Equipment Engineering Capabilities



- APC
- FDC
- SPC
- Recipes
- Yield
- PCS
- E-Diag
- EPT

Partner, Customer Or Supplier



Pervasive E-Diagnostics

Equipment Data Acquisition (EDA) Standards to get Rich Equipment Data

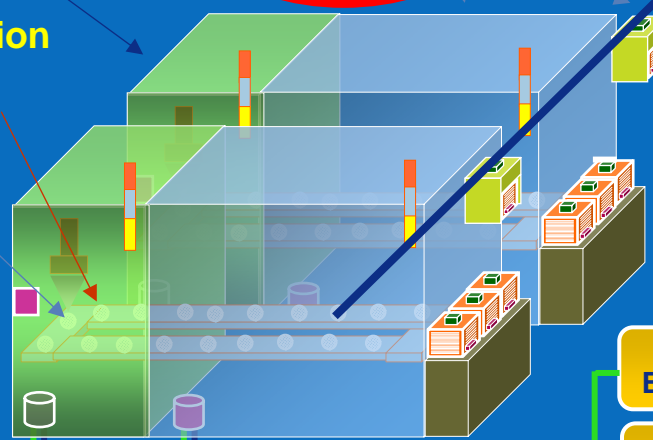
Standard, Detailed Equipment Performance Tracking (EPT) Data

100% Direct Tool Delivery AMHS

Systems Scaled for > 50k wspm

- Manufacturing Execution Systems
- Equipment Control Systems
- Factory Scheduler And Material Control

Offline tools to test schedule rules and rapidly put in Mfg

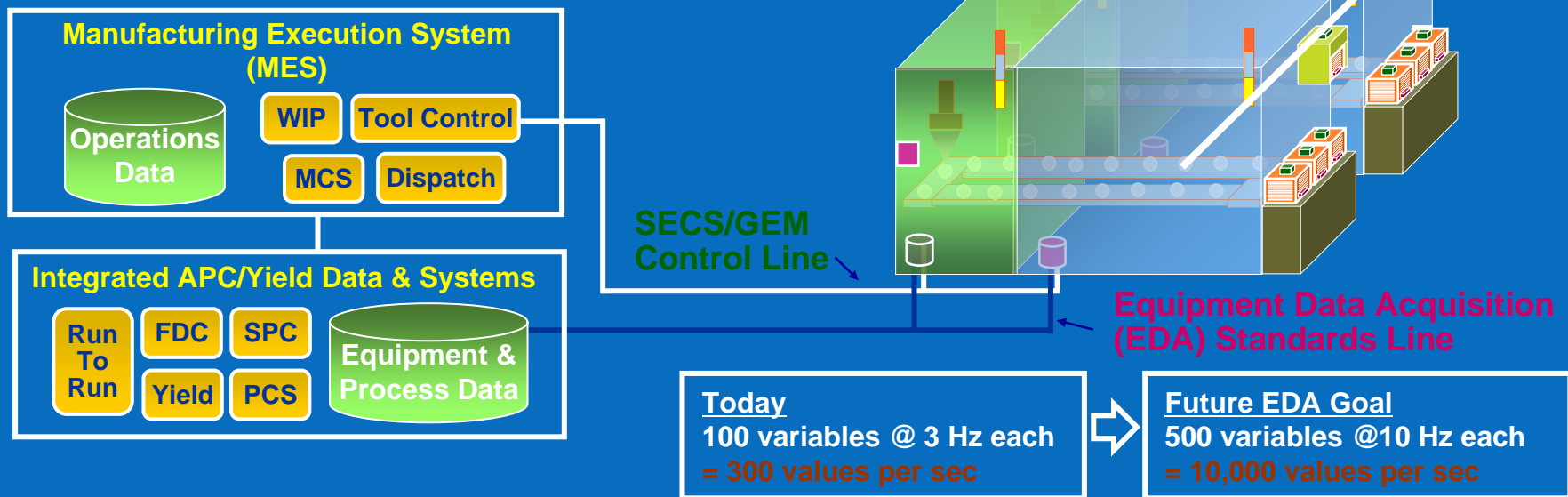


SECS Control Line





# Future Process Control System Capabilities



## Automation Capabilities

1. Data Sharable between APC applications
2. High data transfer rates
3. Single point configurations
4. Integrated yield, process control, and operational systems
5. Rapid application development (run to run algorithms, etc.)

## Equipment Capabilities

1. Standardized data and connectivity
2. Fast sensor sampling & data transfer rates
3. Host ability to stop processing as needed
4. Graceful recovery when a fault occurs
5. Ability to change parameters and values between wafers
6. Wafer tracking all points within the tool

# Factory Integration Requirement Drivers

**Cycle Time Reduction & Operational flexibility**



**Cycle Time/Operational Flexibility:**  
Multiple lots per carrier and/or fewer wafers per carrier. Get new products to customer much faster.

**More good wafers out per tool**



**Output per tool must increase:**  
Find breakthrough solutions that result in significant increases in good wafer out and increased OEE (eg: APC, e-Diag)

**Highly automated factory**



The 300mm factory is much more **automated** and must be designed to transport hot-lots and hand-carry's.

**Reduce Time to Money**








**Reduce time to \$\$\$/Cycle-time reduction:**  
What are stretch goals for cycle time from ground-breaking to first full loop wafer out. How to achieve quicker shrink?

**Factory size is becoming an issue**



**Increased floor space effectiveness:**  
Don't want each new generation to drive big increase in cleanroom size, esp. since fab is segregated Cu/non-Cu and new metal layers added at each node.

# FI Technology Requirements

FI Sub section	Key objectives
 <p><b>Factory Operations</b></p>	<p><b>Speed &amp; Flexibility</b></p> <p>1) Reduce mfg cycle times, 2) Improve Equipment Utilization, 3) Reduce Losses from High Mix</p>
 <p><b>Production Equipment</b></p>	<p><b>Productivity &amp; Cost</b></p> <p>1) NPW reduction, 2) Reliability Improvement, 3) Run rate (throughput) improvement</p>
 <p><b>AMHS</b></p>	<p><b>Efficiency and Speed</b></p> <p>1) Increase throughput for Traditional and Unified Transport, 2) Reduce Average Delivery times, 3) Improve Reliability</p>
 <p><b>FICS</b></p>	<p><b>Reliability and Efficiency</b></p> <p>1) Increase Reliability, 2) Increase Factory Throughput, 3) Reduce Mask Shop Cycle Time, 4) Reduce Costs</p>
 <p><b>Facilities</b></p>	<p><b>Extendibility and Cost</b></p> <p>1) Factory Extendibility, 2) AMC, 3) Rapid Install/Qualification, 4) Reduce Costs</p>

Solution exists
  Solution being developed
  Solution required



# Data Convergence Vision

*The correct data needed by the user to make an informed decision are available at any time both in-situ and remotely*

**Any Time,  
Anywhere,  
Any Device**

**Demand**

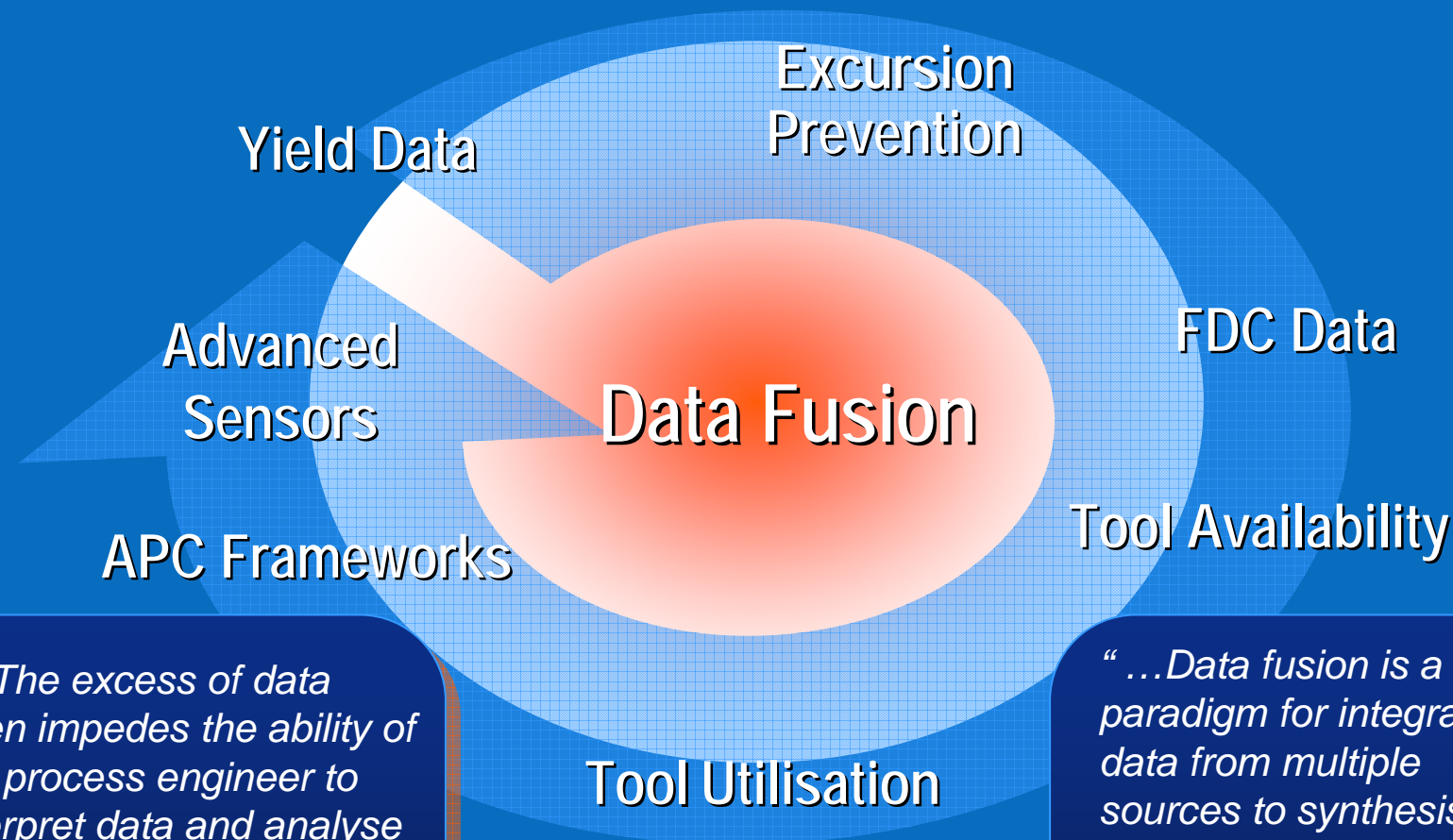
*“Data is pre-processed at each level based on job role requirements using in-line intelligence to ensure an optimised decision making process”*

**COMPUTING**

**Process Data Sources**



# Building the Data Ecosystem

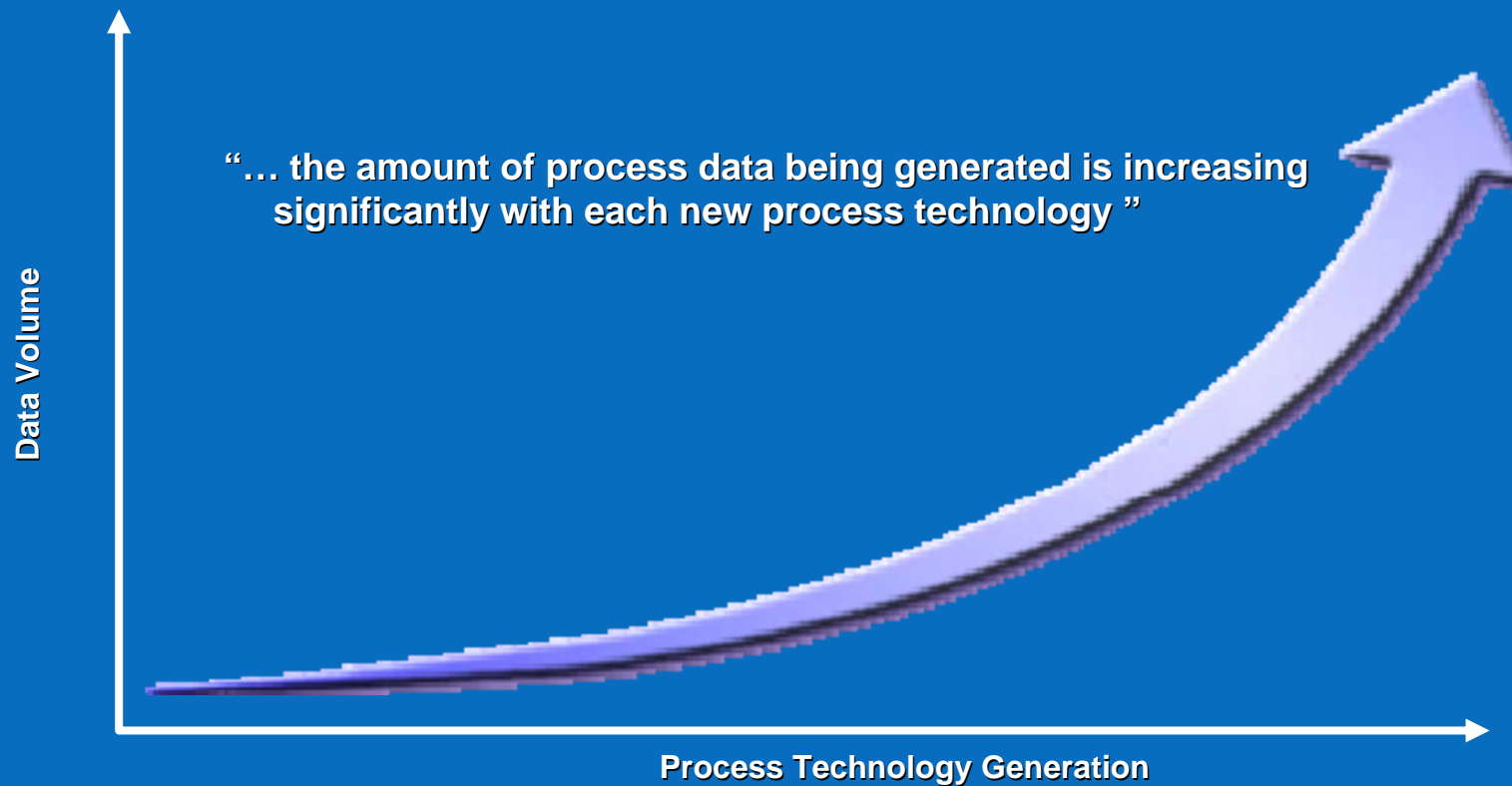


*“...The excess of data often impedes the ability of the process engineer to interpret data and analyse the data. This problem requires the development of new data mining applications...”*

*“...Data fusion is a paradigm for integrating data from multiple sources to synthesise new information such that the whole is greater than the sum of its parts...”<sup>1</sup>*

<sup>1</sup> Lyengar et al 'Foundations of Data Fusion for Automation' IEEE Instrumentation & Measurement Magazine Dec. 2003

# The Data Explosion



Faced with an explosion in the amount of data being generated the standard approach will no longer work.



# Development Focus



*Applications & Human interfaces*

*Business processes And methodologies*

*Data & Information Systems*

*Information & Technology services*

Highly integrated data environments of both structure and unstructured data sets based on standard data formats and data exchange protocols. Increased speed and quality of decision making. Proactive decision making rather than reactive.

# Areas of Focus

## Production Equipment

- Process and Metrology equipment
- Mainframe and process chambers
- Wafer Handling Robots, Load Ports
- Internal software & computers

## Factory Operations

- Policies & procedures used to plan, monitor and control production
- Direct factory labor

## Factory Information & Control

- Data and Control systems required to run the factory
- Equipment and Process Control Systems
- WIP Tracking and Decision support Systems
- Plan, Schedule, Dispatch Systems
- Computers, databases, software outside equipment



# List of Potential Research Areas

3D (Multiple-floor) L/O

Real-time event-driven scheduling

Lot streaming (single wafer processing)

Queuing theory application for CT estimation (CT modeling)

CT reduction:

- a) Variability impact and elimination**
- b) WIP bubble forecasting and recovery**
- c) Design For Manufacturability (DFM) and TPT-Yield trade-offs**

Demand/Data Flow Technology (DFT) implementation

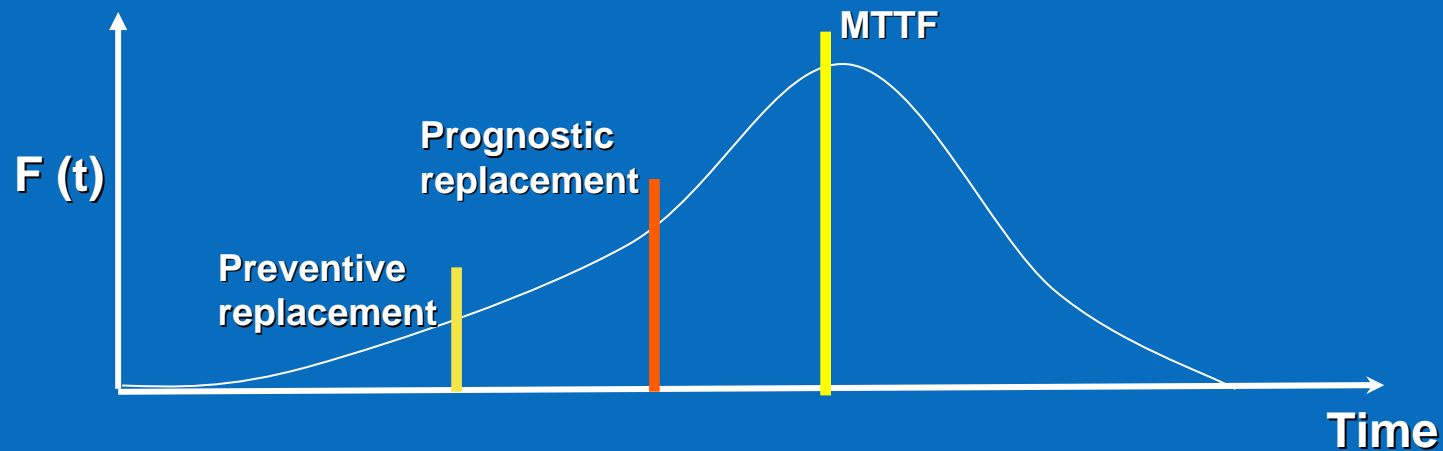
Capacity Planning/Modeling: the impact of multiple constraints

Automated tool-L/O planning

# Iceberg model – Predictive Maintenance



# Predictive maintenance - opportunity



Eliminate equipment variability by moving unscheduled events to scheduled.

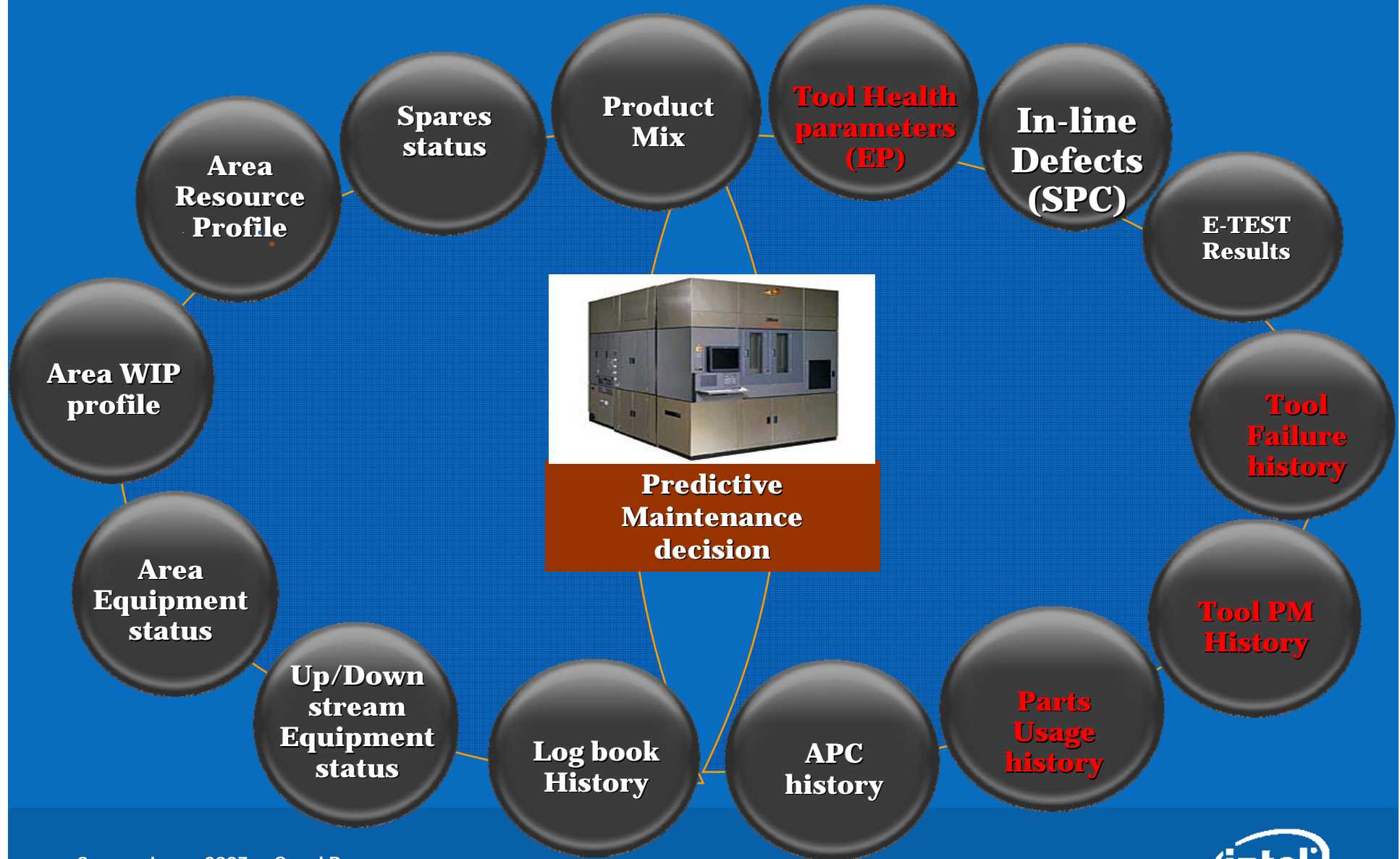
Increased availability by extending time between PM cycles.

Perform maintenance JIT, better resource balancing.

Reduced parts replacement = \$\$.

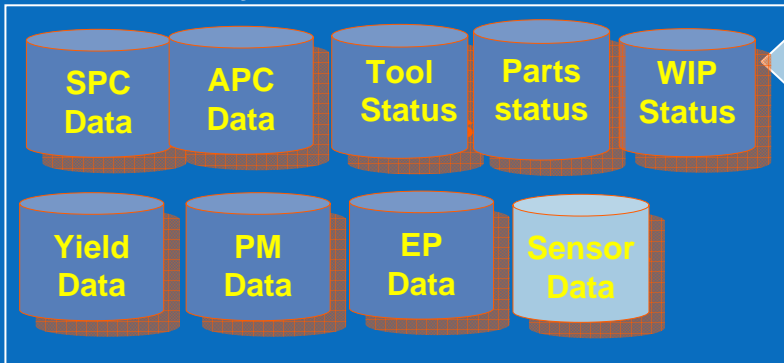
Caution: Need to ensure no Yield impact or CT.

# Predictive Maintenance decision parameters



# Predictive Maintenance vision.....

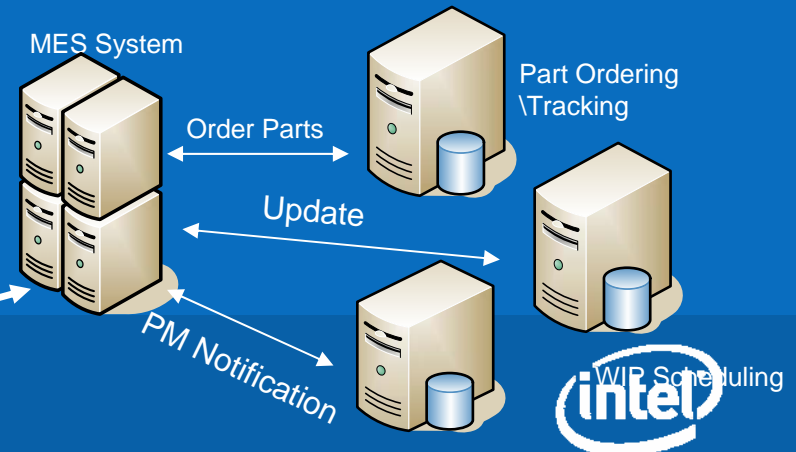
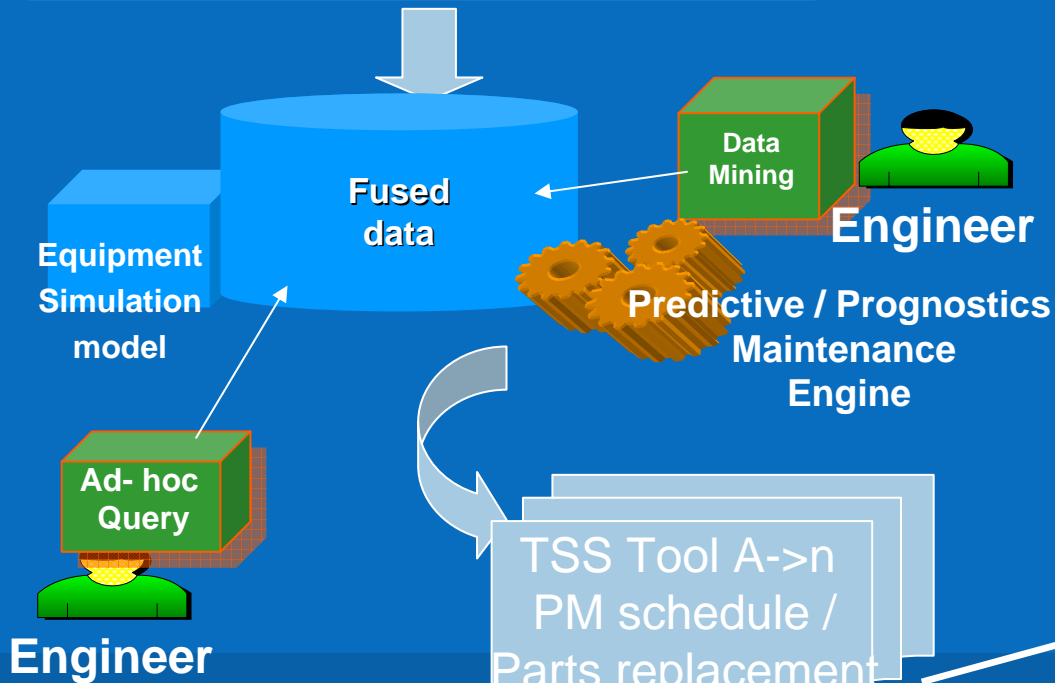
## Factory Data Warehouse Platform



Standalone process data sources fused into factory data warehouse. Facilitate Predictive maintenance analytics.

Factory equipment simulation model integrates with Fused data.

Predictive Maintenance algorithms integrated with simulation data, generate PM schedules & track parts degradation.



# Summary

We have four unique production advantages:

- Technology Pipeline
- Scale
- Agility
- Operational Excellence

We're extending Moore's Law with industry-leading technology

We are enhancing our Manufacturing capabilities through innovation and integration of our core production advantages