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Applying Equipment Simulation for Productivity Improvement – Intel's Experience

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Agenda

Introduction, Simulation Benefits

How we Build Equipment Simulation Models for Best Case Capability

How we Extend the Models for Downtime and Labor Interaction

Challenges and Summary

Presentation Objectives:

Share Intel real-life experience to academia

What is Simulation?

Wikipedia

- A simulation is an imitation of some real thing, state of affairs, or process. …… Simulation can be used to show the eventual real effects of alternative conditions and courses of action.

INFORMS

- Giving you the ability to try out approaches and test ideas for improvement

As practitioner, we use simulation to perform "what-if" analysis and test ideas for improvement

As defined [illegible]

- SIMUL8: A [illegible] real or proposed system
- ProModel: [illegible] decision makers and analysts the ability to run "What If" scenarios of any business process
- Brooks: Simulation allows manufacturers to "look ahead" and perform "what-if" scenarios to solve a variety of manufacturing operations problems such as equipment layout, asset utilization, and workflow issues to name a few
- WITNESS gives you the power and flexibility to model your working environment, simulate the implications of different business decisions and understand any process, however complex

Types of Simulation We Do

Full Factory Modeling (AutoSched AP)

- Entity = lot; all operations in the factory considered

Equipment Level Modeling (AutoMod)

- Entity = unit; only single operation or equipment considered

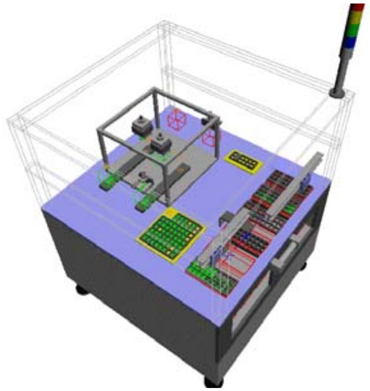
This presentation shares experience in equipment level modeling for Intel's Assembly Test by the Operational Modeling group based in Penang, Malaysia. Terminologies we used here are based on AutoMod

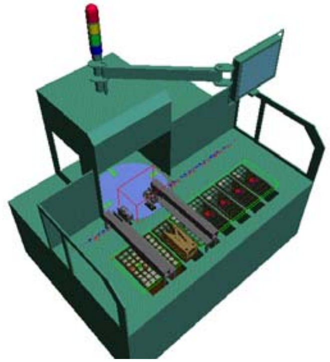
Why Simulation?

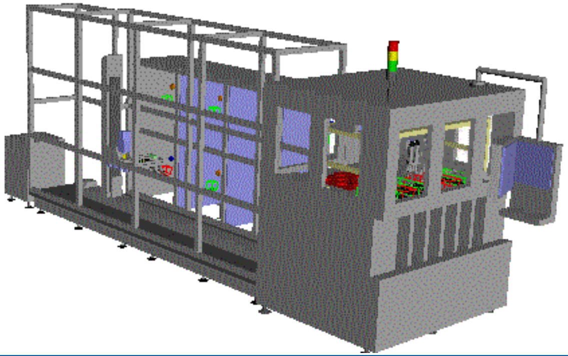
Spreadsheet can't model interaction of highly complex equipment

Accurate capability estimate is key to avoid over/under purchasing of capital equipment

With simulation, we can quantify impact of changes/ideas without any production disruption and verify supplier's proposal







Simulation Benefits

Simulation has produced high confidence equipment capability across different factors (e.g. UPH for different test times) for use in capacity planning

Simulation was able to identify equipment constraint. Once exploited, we can identify and exploit the next constraint and so on…

Simulation experimentation has quantified up to 15% equipment output improvement ideas. When implemented, the actual improvement realized is within what simulation predicted

In some cases, the productivity gain realized has eliminated the need to purchase new equipment

Steps in Building Simulation Models

1. Problem & Objective Formulation
2. Data Collection
3. Model Development
4. Verification – test the worth of model
5. Validation – compare model to real-world data
6. Model Experimentation
7. Result & Implementation

**These are taught in universities.
We'll share how we apply it so that academia can relate theories to practice**

Our Approach in Equipment Modeling

1. **Build detailed best-case UPH models** — Capture detailed equipment motions
2. **Apply model to improve UPH** — Predict best-case UPH, improvement ideas, identify constraint
3. **Extend model for downtime and labor consideration** — Comprehend labor interactions due to setups, monitors, repairs, assist, etc.
4. **Apply model to improve output** — Answer question "what's the achievable output"

Why?

Deliver incremental small wins and earn credibility

- This is important especially for a new simulation group
- Trying to build complete model will take a long time – will lose many intercept opportunities to apply simulation. Customers will try to get answers through other methods (e.g. spreadsheet models)

Align simulation resources to answer the most relevant questions

- Improve UPH and look at waste elimination opportunities due to man-machine interactions to get the most out of our equipment

Questions Before Starting Simulation

Does the question to be answered require simulation?

- If problem is too simple, consider using mathematical model instead
  - Simple spreadsheet formulas work for simple problems

Can simulation model answer the question?

- Understand decision intercept & agree on resources and time needed to build the model. If cannot meet customer requirement, tell upfront
- Set the objectives, questions to be answered
  - Good examples
    - To improve the equipment output, to evaluate supplier's proposal
  - Wrong examples
    - To optimize equipment – simulation is not a tool for optimization

Identify management sponsor

- Helpful to remove roadblocks, get resources required, etc.

Building High Fidelity Equipment Models

Get layout drawing, equipment manuals & pictures, and observe

Break the equipment into major modules and build sub-models

- Use kinematics to represent robots
- Use conveyors to represent conveyor systems and path mover for pneumatic or simple/fixed movement
- Use static drawing to represent non-moving parts of the equipment

Observe the equipment and capture actions into video

- Use video for time study (i.e. time taken for each conveyors, robots motion) which the simulation model will be made to match
- When equipment is complex, get the detailed logic from equipment supplier. Use equipment log files if available
- For new equipment being developed, use design specifications

Model Development Considerations

Products-dependent parameters

- Media density (e.g. JEDEC tray)
- Machine parameters based on product (e.g. speed, recipe)
- Don't hard code – put parameters into input data file

Model reusability

- Common sub-models should be designed so that it can be used in various types of equipment (e.g. loader, unloader)
- Discipline in putting comments in codes

Model Factors, Response

- Read simulation factors from input data file
- Add codes to collect the relevant statistics (e.g. UPH)

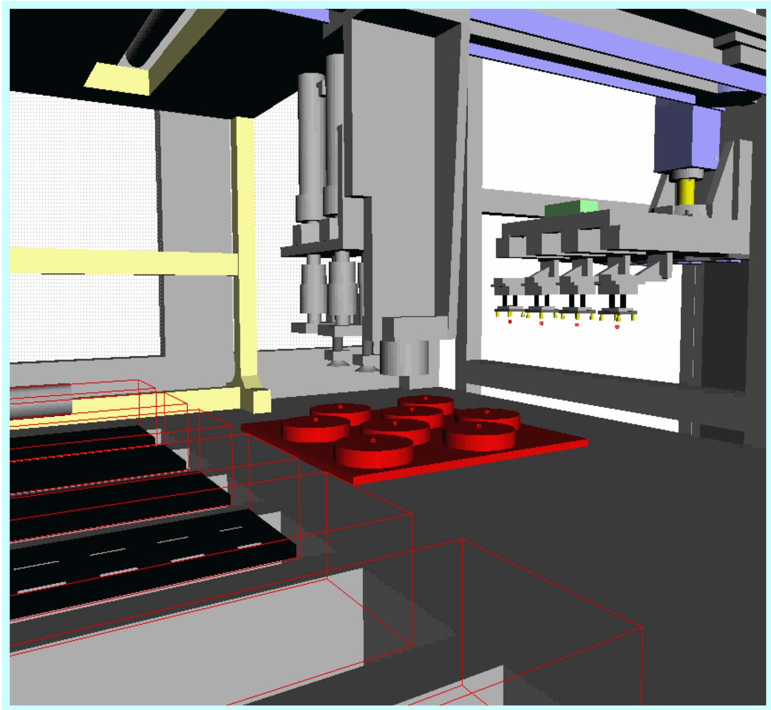
Model Development (cont'd)

Coding for simulation is different from VB, C/C++, etc.

- Entities execute the code
  - There's no main() function – the code will not run by itself
  - Entities are sent to procedures to start its execution. Procedures can clone or transfer entities to other procedures
- Similar to coding for multi-threading/tasking
  - If global variables are used by multiple procedures, need to have exclusive read/write control (e.g. semaphore)
  - A procedure may be executed by multiple entities, e.g.
    - There are multiple service counters
    - The procedure to service each customer is exactly the same
    - When the customer (entity) enters simulation, regardless of which service counter it goes to, it enters the same subroutine

Model Verification

Our high fidelity equipment simulation models look and behave like the actual equipment as illustrated below. We demonstrate simulation animation to equipment engineers to verify the model



Model Validation

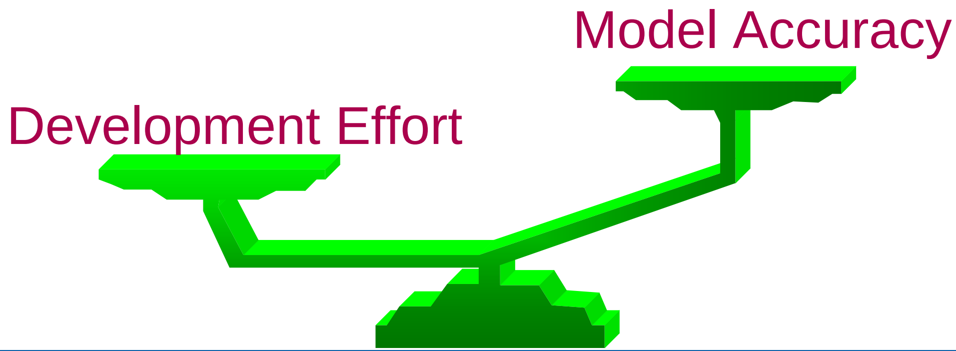
Match each sub-model with logic and time from video. Integrate the sub-models and match the logic and time again (interaction)

Simulation output / performance metrics must be known before validation

- For UPH prediction, compare UPH between simulation and actual

Agree on expected simulation model accuracy

- Need to trade-off model accuracy and development effort
- Typical accuracy: large models > 90%; small models > 97%



Use of Best-Case UPH Models

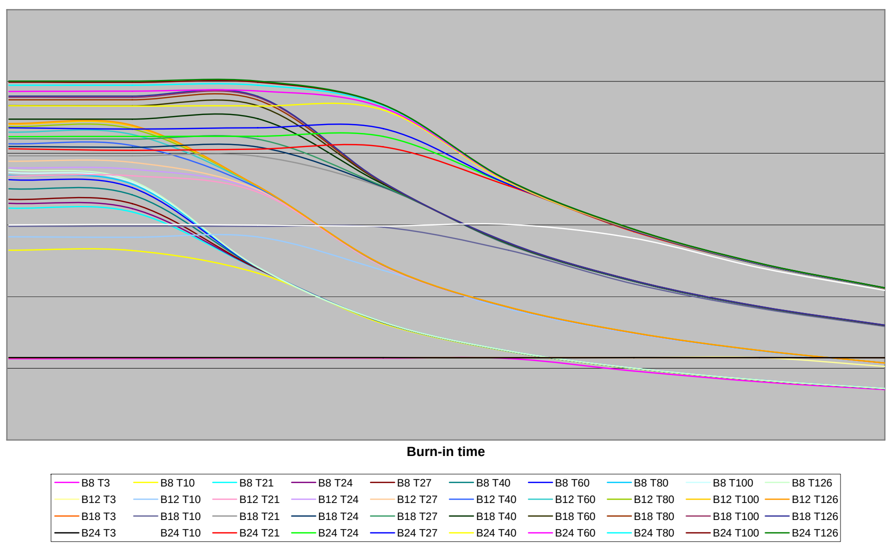
Best case UPH models are used to quantify the best case equipment capability with no downtime and no wait for operator and materials

Why the need for simulation for best case condition?

- Lotsize, lot setup, processing time differ by product
- It will be impractical to test all scenarios on the equipment upfront

In general, full factorial simulation experiments are performed
- 1 hr model warm-up
- 1 week run
- Replicate if system has variability

UPH with different media densities



Pitfalls of Best-Case UPH Models

In real life, there will be

- Assist, repair and other interrupts
- Interaction with operator and technicians
- Product conversion
- Lot setups, metrology, and monitors/real-time inspections

So if someone asked "what's the achievable output per shift?", the best case UPH model will not be able to answer that

Extending the Best-Case Models

Since the models have all the necessary details, comprehending the other activities can be seen as extending the UPH model

- Add capability to “take down” and “bring up” each sub-model with synchronization with the upstream & downstream equipment. Ensure it works when all components of the equipment are running
- Add control points where operator and technicians will interact with the equipment
- Connect the control points with paths
- Add vehicles (operators and technicians) into the system
- Develop codes to control shift change and break time of vehicles

Test model with single equipment

Extended Model with Single Equipment

Simulation input parameters

Tool parameters
Conveyor speed
Index & delay times
Process & pnp times

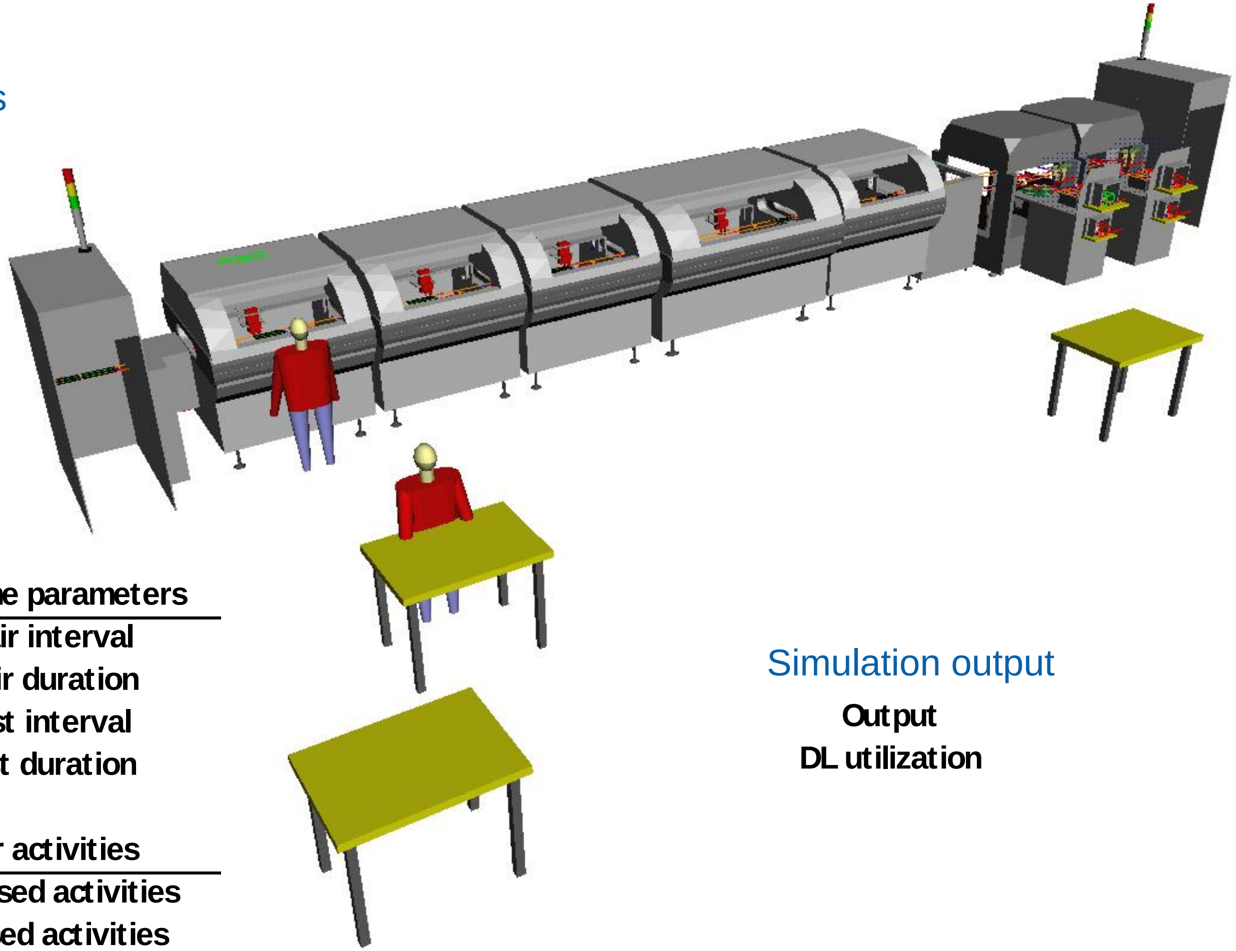
Run parameters
Hours per shift
Hours per week
Simulation run length

Lot parameters
Lotsize
Carrier density

DL parameters
Break calendar
MS & MTE per link
MS & MTE efficiency

Downtime parameters
Repair interval
Repair duration
Assist interval
Assist duration

Labor activities
Time-based activities
Lot-based activities
Run-based setup
Lot setup
Measurement



Simulation output

Output
DL utilization

But…

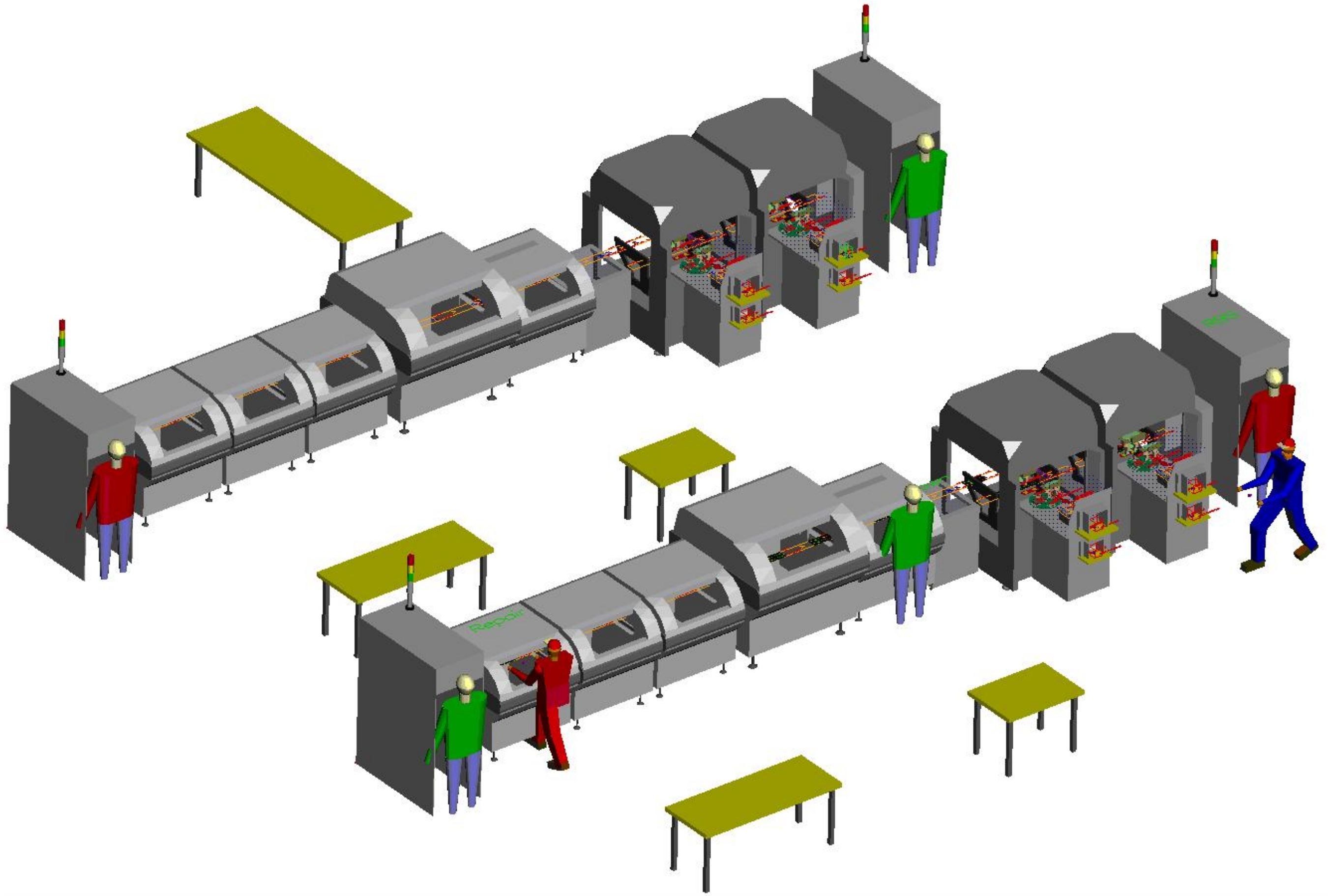
In real life, the operators and technicians are assigned to run many equipment

To mimic this, a functional area (multiple similar class of equipment) need to be modeled

Other considerations in the model

- Path must connect to adjacent equipment and shared resources (metrology tool)
- Some operator may be dedicated to a specific equipment while others can float around
- Technicians are typically global resources – they are not dedicated to any specific equipment

Extended Model with Downtime & Labor



Model Development Considerations

Design codes for reusability

- If designed correctly, the exact sub-model can be repeated without any code changes – equipment specific parameters can be read from input data file

Shift and break time controls are done at global level while labor activities controls are done at sub-model level

- Countdown timers for repair and assist operate only when equipment is processing parts. This is to ensure equipment will not go down when it is idle
- Need to preempt labor activity when break time or shift end is due

In summary, to make the model usable, we need to comprehend what we see happening on the production floor into the model

Verifying & Validating Extended Model

Model verification can be done by visually observing the simulation animation and comparing it with what's supposed to happen

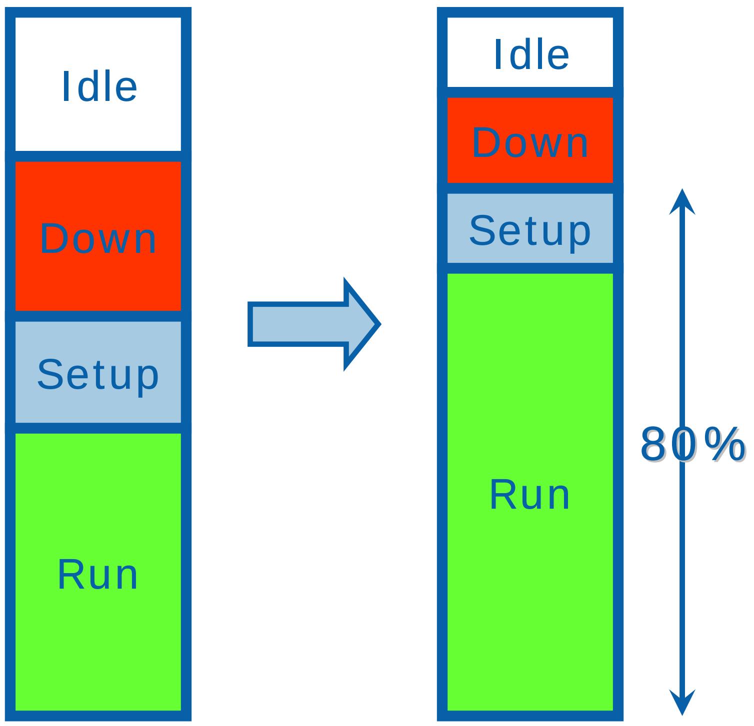
However, model validation will be much harder now compared to best case UPH model. Why?

- Operator to operator and technician to technician variability exists – different skill level, alertness, response time, walking speed, etc.
- When we observe the equipment with operator and technician interaction, they may behave differently (e.g. performing their best)
- Assist, repair and other interrupts have variability as well

We normally use multi-observation study (MOS) to track operator and technician utilization for comparison with simulation

- Use predetermined downtime from observation in simulation

Use of Extended Model – Improve Tool Utilization



Reduce down time

- Reduce assists, failures
- Reduce awaiting operator/technician

Reduce idle time

- Avoid material shortage
- Avoid operator unavailability

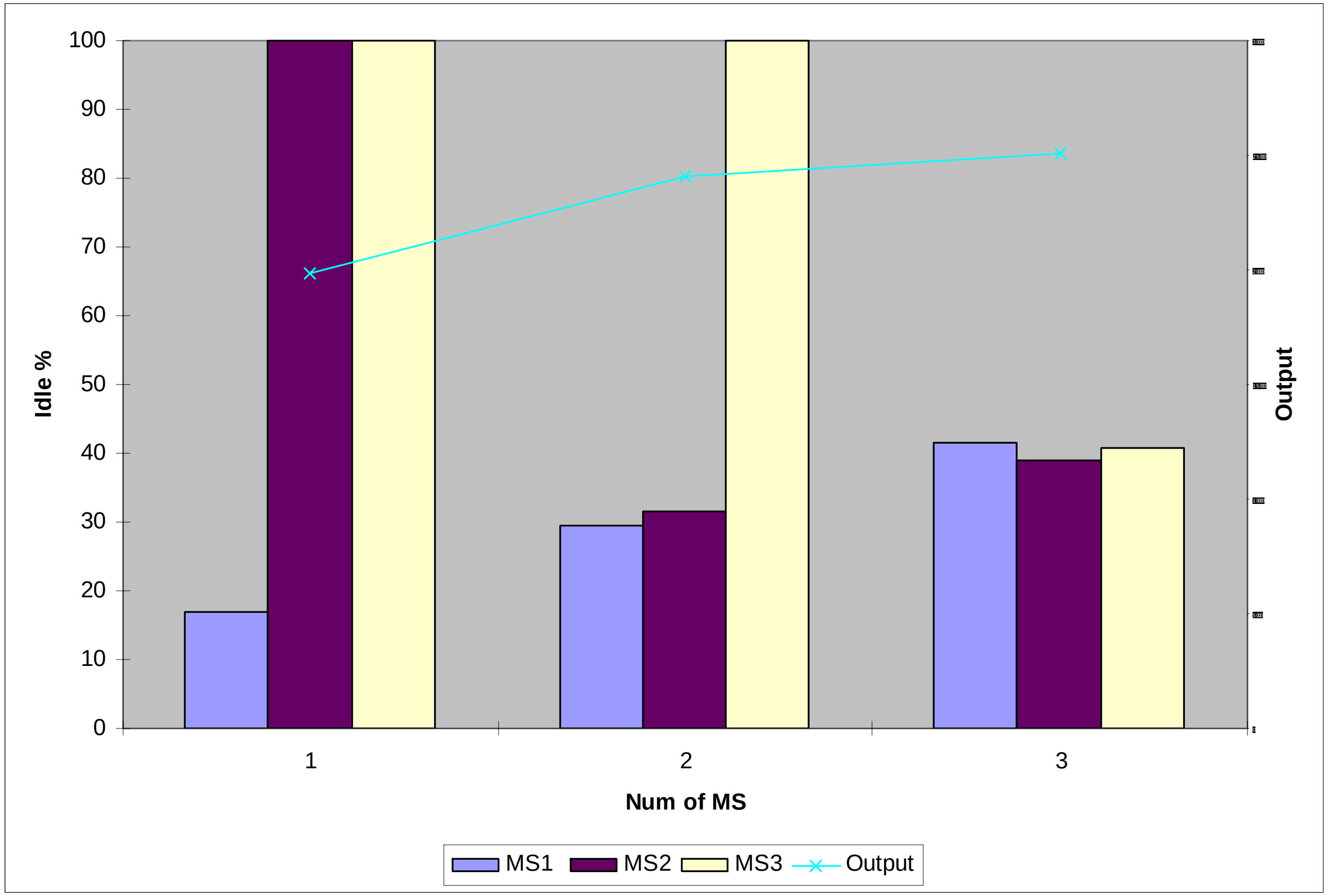
Reduce setup time

- Optimize job sequence
- Run optimal lot size

Others

- Reduce yield loss & rework
- Reduce work pace & skills variation

Use of Extended Model – Required Labor



Summary

Deliver incremental wins and extend the simulation models to answer questions the management wants to know

- No ‘big bang’ approach
- Show results to earn credibility

Design models for reusability and extendibility

Have agreement with stakeholders on balancing model development time with model accuracy

- Applying the model to intercept key decision points is key