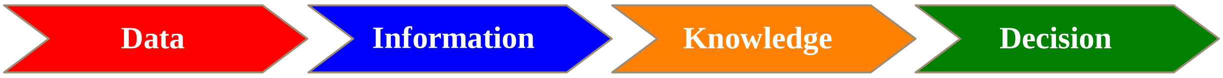
Knowledge Hierarchy



Data – the raw numbers or images provided by the measurement tool (from the Latin, it is "the thing given"). It is a collection of numbers with units and with estimates of uncertainty.

Information – data in context. Information includes sufficient details of what was measured where and when so that it can be easily discerned from other similar collections of data. It is organized and accessible. Information may also include the filtering out of extraneous bits of the data or distilling the numbers down as much as possible (reporting a mean and standard deviation, for example), where appropriate.

Knowledge – an interpretation of the information based on an understanding (that is, a model) of cause and effect. Whereas information answers the question of "what", knowledge answers the question "why".

Decision – acting on the knowledge obtained to achieve some benefit.

Moving up the knowledge hierarchy means moving from the specific (data) to the general (a model). This is what data analysis is all about.

- Given a set of data, are you extracting the most knowledge possible? Are you making the best possible decisions?
- How can you *plan* an experiment (data collection and analysis) to ensure a good decision can be made?

The Five Step Decision Making Process

1. Preparation (planning) – be prepared to turn data into information, with a specific model and decision in mind.
2. Measurement – generate the data, minimize the uncertainty, and keep track of the context.
3. Analysis – using a model, turn information into knowledge (i.e., assign a probable cause to what is observed).
4. Decision – with an estimate of the uncertainty in the analysis results, perform a risk/benefit analysis to determine the best decision.
5. Post-mortem – have we learned anything from this experience that we can use to do things better next time?

Note: moving up the knowledge hierarchy is an iterative process, with feedback loops. Don't let the linear "hierarchy" nomenclature fool you into thinking that this is a linear process.

Example Data-to-Decision Process

Measuring overlay (the accuracy with which one lithographic layer lines up with a previous layer) during semiconductor manufacturing and determining whether the measured wafers pass or should be reworked.

I. Preparation
   A. Define the metrology tool to be used
      - Required precision, accuracy and throughput
   B. Design the measurement target
   C. Define the within-field sampling plan
   D. Put measurement targets in the chip design
      - Scribe kerf, interdie streets, within die
   E. Define the full sampling plan
      - Fields per wafer, wafers per lot, lot frequency
   F. Create measurement recipe
   G. Create analysis recipe
      - May include reticle data, lens distortion map
   H. Create overlay spec for lot pass/fail
      - Spec is intended to reflect device yield/performance
      - Spec may depend/influence sample plan, tool specs, analysis approach
   I. Define the process (action plan) that applies the spec in production

II. Measurement
   A. Print wafers
   B. Transport wafers to overlay tool and load
   C. Select wafers to measure
      - May be manual or from host or recipe
   D. Make measurements
   E. Perform analysis (usually automatically)
   F. Upload measurement and analysis results to host or 3rd party system

III. Analysis Method
   A. Method 1: compare raw data statistics to spec
   B. Method 2: compare modeled results (model coefficients, modeled max error, overlay limited yield) to specs
   C. Method 3: SPC-like analysis (check for out of control condition)
   D. Apply some combination of above methods
   E. Assess the quality of the data

IV. Decision Regimes
   A. Obvious pass – send the lot on
   B. Obvious fail – rework the lot
   C. Gray Area Options

- Consider gray area as failure – rework the lot
- Shrink the gray area
  - Make more measurements (repeat on same points, increase sample), possibly on a different tool
  - Change measurement algorithm for greater precision
- Apply human judgment (last resort)

V. Decision Post-Mortem

A. For reworked lots, how have things improved?
- Measure reworked lots
- Compare new measurements to old
- Did corrections work as expected?

B. For reworked lots, what is the root cause of the problem?
- What process changes would reduce rework rate?
- Are the processes and tools in control?

C. For passed lots, are things OK downstream?
- Correlation of overlay results to yield
- Is the expected failure rate obtained?

D. Can the overall dispositioning process be improved?
- Relate results to fab metrics (yield, cycle time, throughput, CoO)
- Time to results
- Measurement costs
- Cost of a bad decision