Finding Correlations to Part Quality with eDART™s

Introduction

Users of *eDART*™s often first use them to contain "**Level 1**" part quality problems: short shots, flash and some sinks; characteristics that can be seen without measurement. Simply stabilizing a process and setting alarms above and below the average for peaks or integrals can accomplish this objective relatively well.

Once this is successful you might want to try to contain the less obvious part quality problems. Think of these as;

- "**Level 2**": dimensions, weight, warp, balance and other measurable characteristics that usually do not destroy the part in the measurement but are not visible.
- "**Level 3**" characteristics are those that usually do require destructive testing: strength (tensile, compressive, impact), chemical resistance and such.

We know that most characteristics of injection molded parts can be predicted or "correlated" to in-cavity variables. We call these the "Four Plastics Variables": melt temperature, flow rate, pressure, and cooling (rate and time).

"Finding Correlations" means: Figuring out which cavity variables to force in order to change the parts, how to force them, working the plan (doing an experiment), measuring the parts, finding correlations and setting alarms. This document attempts to describe these steps as briefly as possible. Plenty of literature and courses exist on Designed Experiments that can help you choose more efficient or advanced techniques.

1. Planning

A. What part characteristics are important?
   - Level 2: Dimensions? Weight? Warp?
   - Level 3: Structural or chemical or others?

B. How will you measure those characteristics?
   - Ensure that your measurement equipment and techniques are accurate and repeatable. If possible get the results of a "Gage Repeatability Study" so you know that the measurements will be valid.
   - Ensure that the resolution and accuracy exceed the tolerance requirements by a minimum factor of 3.
   - Find a way to assign numeric inputs to each (e.g. how much chemical resistance?)
   - Do the parts require any post-molding stabilization? How will you make sure this is repeatable?
   - Test your measurement plan on some parts to see that it and how much time it takes.

C. Which plastics variables most likely affect those part characteristics?
   A. Dimensions: Pressure (usually seen in Cycle Integral or sometimes pressure drop); sometimes cooling rate and time in semi-crystalline. Melt temperature and mold temperature are important in crystalline materials. Flow orientation affects dimensions in glass filled materials (affected by gate sequencing). Backpressure and screw design can also affect glass filled materials by cutting up the fibers.
   B. Weight: pressure including packing and then discharge after pack or at end of hold (not controlled).
   C. Warp: Cooling rate; Pressure (static pr. loss); Gate sealed or not (or amount of seal), temperature
   D. Texture: Flow (cavity fill times); First part of pressure (fill and pack times and integrals)
   E. Crystallinity and the properties that are affected by it: Cooling, Melt Temperature, Mold temperature
   F. Contact material supplier for many level 3 properties (impact resistance etc).

   Note: Time constraints may limit the number of variables. Pick those most likely to work. If correlations are weak but some show promise then you can run another study to zero-in on the important variables.

D. Know the process and maintain it. Decoupled? (recommended). I, II or III? Gate Seal? Gate Discharge?

E. Decide how many different levels (values) to force for each plastics variable.
   Usually two levels are sufficient: "Low" and "High". You only need a "Medium" if you expect the correlation to not be a straight line (something with a "bow" in it). It is not a bad idea to have one run in the middle as well.

F. What should you adjust on the machine to force each variable?

   Key Point: It is difficult or even impossible to adjust anything on the machine in order to affect only one plastic variable at a time. Plastics Variables are interdependent in various degrees.

   For example, if you increase fill time but the mold opens at the same time in the cycle then you have decreased cooling time for the last part of the part to fill. Therefore, though it is not standard practice in Design of Experiments to change more than one variable at a time we may have to change two machine variables in order to effectively change just one plastics variable.

   Be very careful with "orthogonal arrays" on machine variables. These can end up changing all plastic variables on every run.

Suppose we wanted to change flow rate as one of our variables. Faster flow rates tend to fill the part farther due to compression. So to get the same fill-only part we might need to change both fill speed on the machine and the V1->V2 position (D3) or transfer position (D2) in order to change only flow rate without affecting the pressurization portion of the cycle at the same time.
This concept applies particularly to transfer position (D2) or slow-down position (D3). When changing fill speeds always go back to a short shot and make adjust the in-cavity position (by weight) to match the value that you found on shorts before the change in speed.

Another key objective is to not destroy the process by changing things that modify the essential elements of DECOUPLED MOLDING℠ (if that is your process setup). Otherwise, if the process is excessively "coupled" you may be changing several or all plastics variables by changing just one machine setting.

G. How much should each value change?
Choose melt temperature and mold temperature based on manufacturer's recommendations for molding, for final part quality (e.g. final part working temperature in semi-crystalline materials) or simulation. For variables such as flow rate and pressure, if you do not know what limits to set use the steps in "2. H" below set the limits. These are done once the process is running. You can also use simulations to suggest limits.

H. Assign a name to each "Run" or "Group".
A "group" is a bunch of parts with the same settings. For each chosen plastics variable (e.g. mold temperature) you may have two groups: one for each pressure; then two more at each pressure at the other temperature, making 4 groups.

It is useful to name the runs with things like "A: High P" for "High Pressure" or "B: High P – Low T" for "High Pressure, Low Temperature". It is common practice to number or letter the runs on the parts and then have a reference document somewhere that lists them.

I. Place the groups in a sensible order of execution for the experiment.
For example: It takes quite some time to change a melt temperature by adjusting the barrel temperatures. Try to do all pressure and flow group changes first, then change the melt and do pressure or flow at the lower temperature. This will save much more time than changing temperature at each group.
Start with faster speeds, higher pressures. Start with lower temperatures. It takes longer to go down than up.

J. Decide how many samples to take for each group.
It is wise to save as many as 10 samples for each group if you have the time (i.e. fairly fast cycle times). You usually do not need to measure them all but you have them if you need them. For long cycle times take at least two to three samples in a group.

2. Running the Processes to Make Correlation Data

A. Before Starting:
- Decide how the parts will be labeled. Ensure that your labeling does not interfere with the part characteristics or later measurements (e.g. markers obscuring a feature or deforming the part).
- Collect supplies: markers, bags, tags etc.
- Plan your part handling, especially with fast cycles and no runners (hot runner). Make a space for each set or lay the bags out in order.
- Plan to stabilize the parts (after molding) in the way that it will be done during production (i.e. cooling etc.)

B. Start the process using standard techniques (Decoupled 2, D3 or other).

C. Stabilize the process in full-auto. Make sure parts are on regular cycle, not sticking etc.

D. Be sure to set the fill volume on the eDART at the slow-down to pack (D3) or transfer (D2). This will provide accurate records for fill speed / flow rate and viscosity as well as other variables.

E. On the Sequence Settings "Cavity Fill" tab choose the sensor and pressure level that represents a full cavity. Usually this is 1000 psi at the end of the cavity. But if you only have sensors at Post Gate or Mid Cavity then change the sensor location and level as appropriate. This creates good data for cavity fill times and balance.

F. Likewise on the Sequence Settings "Cavity Pack" tab choose the sensor and percent of peak that represents a fully packed cavity. If you are using all Post Gate sensors then the default Post Gate is acceptable. If you have just Mid Cavity or End of Cavity sensors in each then change the sensor location as appropriate. If the pressure curves have very gradually rising tops lower the percentage for pack to ensure it does not pick up 98% at the wrong point.

G. On the Sequence Settings "Other" tab choose when the integration limit should end and whether to compute peaks outside of injection. The default is at the end of mold clamped. If you intend to run on machines that do not provide this sequence signal you can choose a fixed time or end integration at the end of screw run (both

boxes not ticked). However if you expect that the cavity pressure data between the end of screw run and the end of mold clamped to be useful then use one of the settings to set a fixed integration time.

H. If not already chosen determine the limits by adjusting the process as described below. This is only necessary if you are unsure how much variation the process can handle without becoming unstable or exceeding the capabilities of the machine. It is not necessary to use the maximums in order to get good correlation.
   1. Build a centered process that can withstand reasonable variation in the values chosen above.
   2. Save a template for the centered process. This helps to ensure that you have stabilized between runs.
   3. Change the settings until one or more of the following occurs:
      - Parts are visually unacceptable: short, flash, blush etc.
      - Anything causes cycle breaks such as nozzle drool (mold protect), parts sticking or difficulty ejecting.
      - Speeds or pressures exceed the machine's capability (e.g. pressure limiting fill or pack) or the capability of any machines on which you expect to run.
      - The machine ceases to perform as instructed (e.g. will not control speed or pressure, nozzle leaks).
      - The process is no longer robust; e.g. not decoupled (fill so fast that the flow front reaches the end of the cavity before slow-down) or unstable due to very low viscosity from slow fill rates.
   4. Choose levels just inside these limits to give you the widest possible window for testing. However you may know from experience that certain values of cavity variables are unacceptable. If so then narrow the limits accordingly.
   5. Record the chosen Setting Levels with each group as defined in "1., G & H" above. Record each limit for each control parameter (machine, temperature, VP->P transfer etc.) that you will be changing.
   6. Return the process to the centered process and make sure that the data matches the template from 2.

I. On the *eDART*™, start the Part Sampling tool and select "Start New Data File". Do this only once at the start of the experiment and then once at the end, not for every sample. The switch to make a new file for each group is only for periodic sampling during production, not for correlation sampling. Make sure it is un-ticked.

J. Create a note on the Summary Graph (at the end, after you broke the file).
Include such things as the purpose, equipment in use (machine, cooler, etc.), initial machine settings & so on.

K. Since the process has been running for some time check the Summary Graph for stability. *Effective Viscosity / Fill* is a good all-round first check. Other useful data are cavity pressure integrals, mold temperature minimums, screw run time, cycle time, and *Average Value / Backpressure*. We have seen situations where the machine or auxiliaries are causing instabilities that can affect the results. Look for trends or cycling in the data.

L. Enter the name of the group (or "run"). This would be the short name that you created in "1., H" above. You can put details in the notes area and they will become part of the note that marks the group.

M. Press "Start Sample" on the Part Sampling tool and do what it says. Do not save parts until it explains which one to take out. Always dump any accumulated parts up until it says "Take Next Sample." If the "Reject Samples" switch is on and you have a part diverter then all sampled parts will go into the reject chute.

   Do not press "Stop Sample" unless you mistakenly started it. Wait until it says samples are completed.

N. Bag, number or label the parts in each group. Remember to put the group name on or with the parts.

O. Optional: Return the process to the centered process before changing settings for the next run. Check the template to make sure it matches the one you saved in "H., 2" above. This will ensure that nothing else outside of your control has changed that would affect the experiment.

P. Adjust the process for the next run and repeat steps L through O above. Do this for each run.

   NOTE: Do not stop the press between samples. It must run continuously to keep the stability achieved in C.

Q. If the machine is to continue running the job after all samples are done then click "Start New Data File" again. Otherwise stop the job on the eDART. Now the whole will be in one set of files with the same base name.

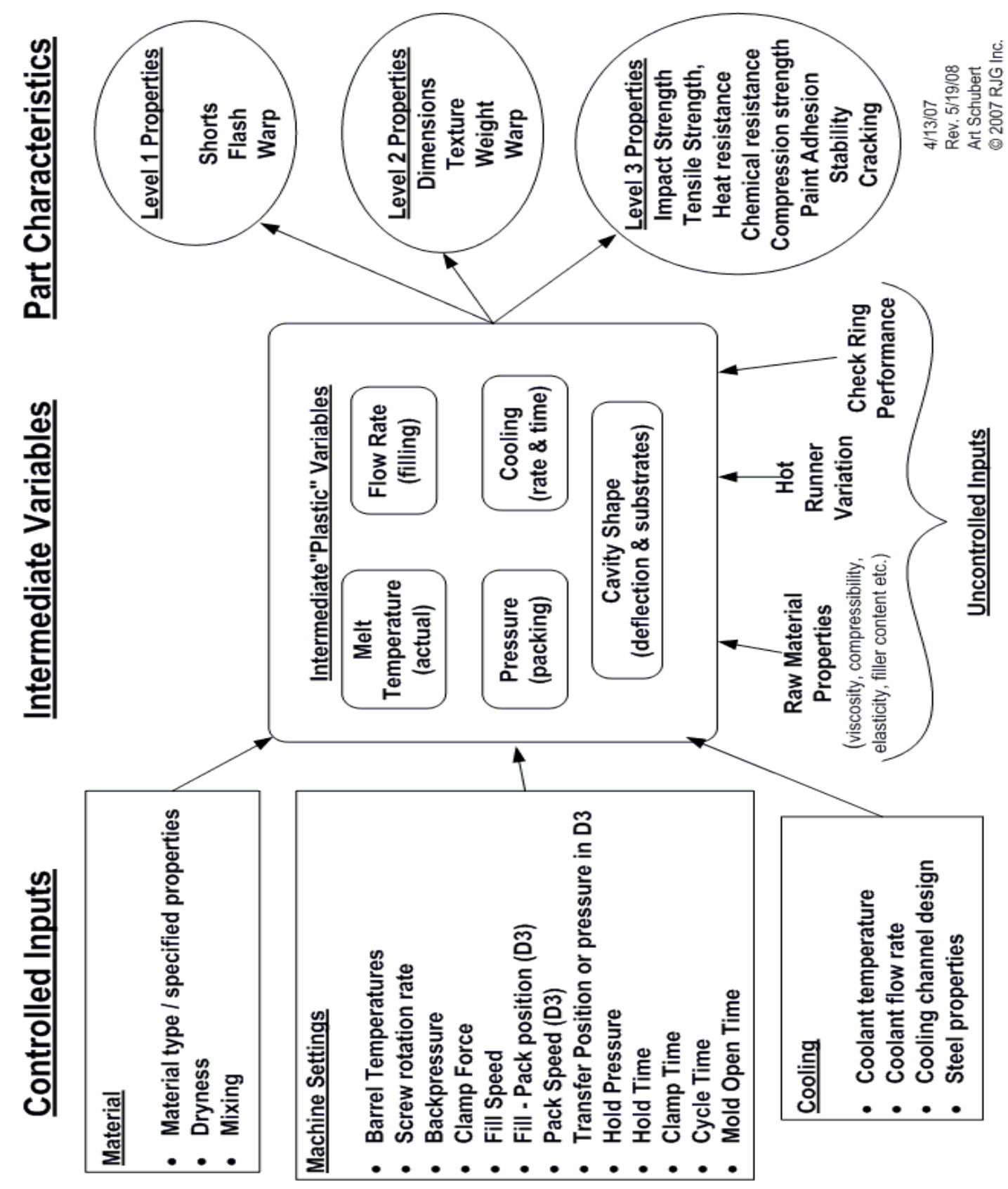
3. Evaluate the Data

A. Transfer the data to a Windows computer.
B. Measure the parts.
C. Use the techniques described in RJG's "Auto Correlator User Guide" to enter the part measurements, find correlations and set alarms.

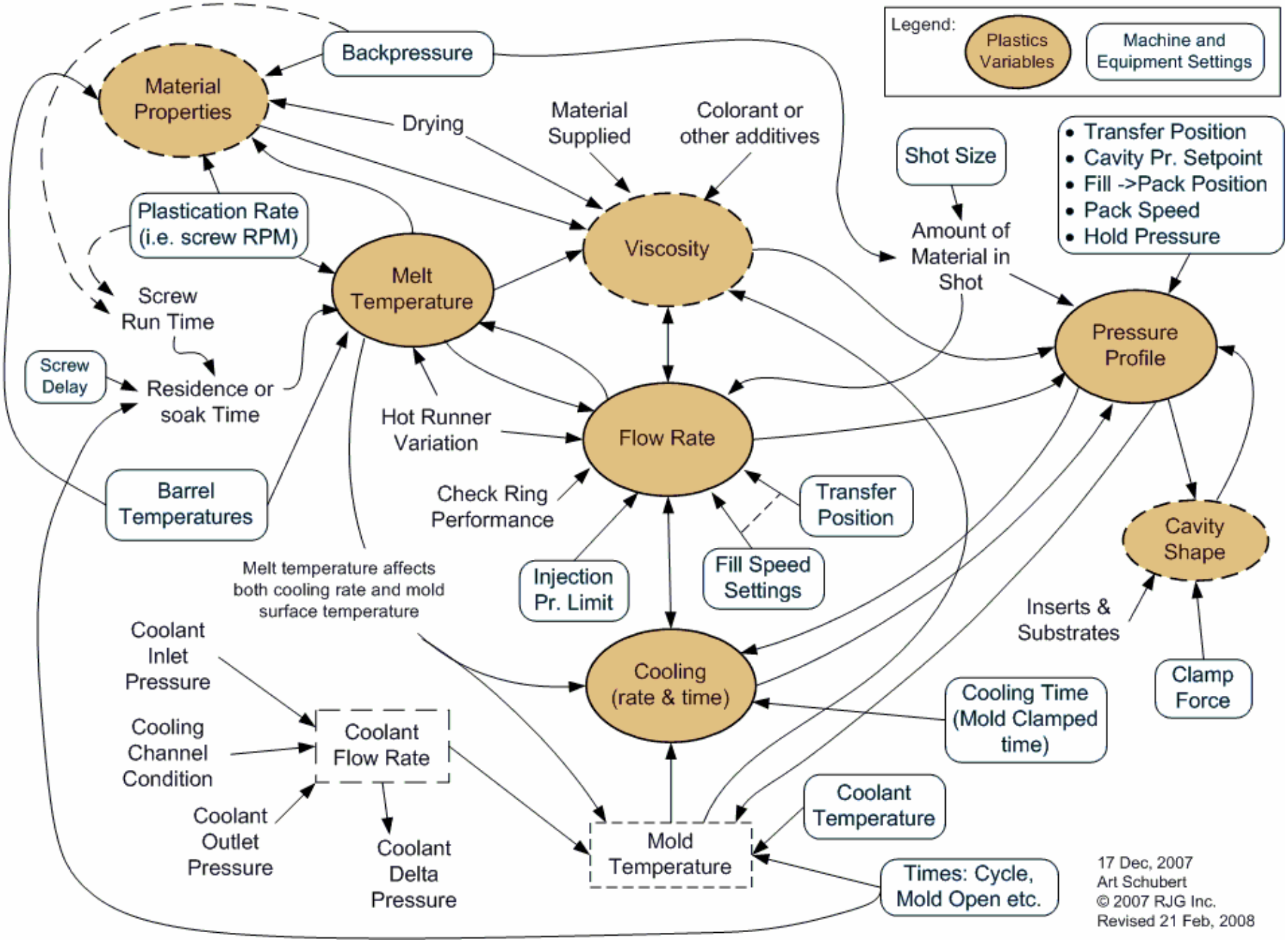
   Note: If all of the measured parts fall within specification then the alarm limits can be set to the values of the cavity variables discovered in 2. H. above when you set the limits for the experiment.

D. After the alarms are set adjust the process up and down to ensure that the bad parts are sorted properly.

The attached sketches illustrate the plastics variable / part / machine relationship and their interdependence.



Not So Independent Variables in Injection Molding



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