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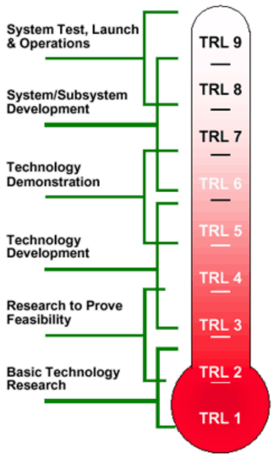
Path to sensor commercialization

This model is an overview of the work needed to develop a sensor from idea to product. It is based on the experience of Sparv Embedded sensor product development and discussions with other sensor developers. The document is a tool to help plan the process, not as an authoritative instruction. Real-world projects often repeat phases several times while requirements and limitations are discovered and overcome.

The goal of the process is all materials needed to manufacture and sell the sensor at scale, or to find out as early as possible if this is unviable to minimize the loss of an unsuccessful project.



This model mimics the Technology Readiness Level (TRL) scale but is more specific in addressing key points for sensor products.

Illustration from Wikipedia.

Types of commercialization

"Sensor commercialization" comes in three forms that are all valid for this discussion:

- **New transducer hardware**. This may use new materials or even novel sensing principles.
- **Packaging existing sensors** in a new combination. Example: Using multiple off-the-shelf (COTS) magnetometers to detect the position of objects.
- **Calculating a new unit of measure** to enable new utility for a sensor. Examples: Calculating Air Quality Index from a less expensive sensor. Calculating traffic from crowdsourced cell phone sensors.

In the latter two cases, "sensor characteristics" refers to the behavior of the novel assembly or calculations, not the sensor elements themselves. Here more emphasis will lie on evaluating the product in the intended environment.

The use case is an integral factor

Some market requirements have a big effect on how far along the sketched path the development must be carried:

- **Interface** -- options range from analog signals requiring additional front-ends, to a fool-proof consumer product that only takes minimal training.
- **Data quality** -- as discussed in the "Characterization" paragraph below.
- **Target production volume and cost** -- this determines what extra investment in engineering (NRE) is needed even after a working sensor design is complete.

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Phases

1. Proof of concept

Lab setup that measures the property under convenient conditions.
Goal: Demonstrate the principle of measurement and key measurement properties

2. Working prototype

Free-standing device used in realistic field setting. The device is built in a number of units. Not optimized. May deliver raw values that need manual processing.
This phase investigates the interaction between sensor, the support system around the sensor and the environment. Ideally, the prototype delivers useful data when handled by experts and is used in internal projects.
Discussion of competing methods and products and their relative price, performance and other properties.
Goal: Demonstrate the viability from a usability point of view, together with other interacting parts (such as airframe, power, related sensors). Understanding basic limitations involved.
Examples of disqualifying results: The sensor will break too easily for its intended use. The sought parameter can not be measured with the planned strategy. The sensor has unrealistic power requirements. The sensor leaks hazardous materials or radiation or becomes too hot for safe handling.

3. Realistic performance

Designed with all critical components the same as future low-volume production, but not necessarily in an optimized package, or optimized for cost, size, weight or ease of use.
Includes electronics and software: AD conversion, specification of calibration parameters and formulas.
This takes a more detailed understanding of the limits of physics and available components compared to the previous phase.
Demonstrate the sensor running for an extended amount of time.
Demonstrate what resolution and reproducibility are attainable in a field setting and not only in controlled conditions.
Goal: Design producing the most reproducible and high-resolution raw data, with indication of real-world performance.
Examples of disqualifying results: The intended use introduces insurmountable amounts of noise. The sensor or the development is too costly to be worth the resulting data. Other sensing techniques are more promising.

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4. Laboratory profiling

Comparison with reference instruments under controlled conditions that simulate the range of target conditions.
Demonstrate level of variation between different units. Manual calibration as accurate as possible to explore the limits.
Profiling: measurement repeatability, jitter, response time, cross-sensitivity with other parameters. Sensitivity to ESD, supply ripple, environmental factors like temperature, etc.
Mechanical: Specify what manufacturing tolerances, stability and shielding are required to attain the stated quality.
Goal: Estimated sensing performance, product properties and production costs (See “commercial factors” below)
Examples of disqualifying results: The translation from raw data to final data is not accurate enough. Outside factors affect the final accuracy, curbing the use of the sensor too much.

5. Commercial viability study

Determine the economics of continuing development from an internal tool to a generally available product. A thorough study includes a list of pros and cons comparing the product with other options available to potential buyers. This should identify product "USP" (Unique Selling Points) that narrow down the realistic market. A list of named customers that have expressed concrete interest is also useful as independent validation of the market.
See “commercial factors” below.
Goal: A decision to continue or abort. Continued strategy and budget.

6. Low-volume manufacturing

Refine electronics design to improve size, weight and power requirements and enable automated pick-and-place electronics production.
Design manufacturable enclosure to address fragility, protection against elements and solar radiation, handling by intended users, etc.
For internal use, written instructions for assembly and calibration, which can be followed with limited training.
Work on ease-of-use for customers. Software that can be used by non-experts. Implemented method of calibration, and automatic application of calibration parameters to produce final data.
Goal: Get experience of manufacturing and all related costs. Enable early external users to evaluate data quality, usability and get early real-world utility.
Examples of disqualifying results: Time-consuming manual manufacturing steps cannot be automated, making series production too expensive. The usage instructions are too complicated to teach non-experts.

7. High-volume manufacturing

Engineering to optimize the design and scale the production and calibration process. Improved user experience. Procuring components in volume.
Goal: Profit and gains for science and society

Commercial factors

The following aspects play a role in the demand for a product and should be considered when designing the product:

- Sensing performance (reproducibility, precision, hysteresis, response time, cross sensitivity, ...)
- Product properties (ease-of-use, usage limitations, power consumption, size and weight, recalibration period, ...)
- Product price
- Amount of marketing
- External factors (legislation, trends, etc)

Analyzing the full commercial picture is the matter of a general business case. This assesses factors like investment capital, marketing costs and effectiveness, market risks and opportunities, pricing strategy, current and future competition, available market at different price points and levels of product maturity. While important to consider, these are outside the scope of this document.

Documentation

The following documents are refined as the project moves through its stages. A final product requires all documents to be finalized. The status of these documents can be used as metric for the progress of the product development.

For internal use:

- Sensor characterization
- Electronics design, manufacturing bill of materials (BOM) and assembly instructions
- Mechanics design, manufacturing bill of materials (MBOM) and assembly instructions
- Firmware source code, build instructions, binaries, flashing instructions, programming jig
- Factory test and calibration instructions and facilities
- Production cost break-down
- Pricing for distributors and MSRP (or MAP), with possible discounts based on volume or market
- Applicable certification (CE, FCC, relevant ISO)

For public use:

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- Marketing material (flyer, pictures, web page, case studies)
- Datasheet (size, weight and power (SWAP), data characteristics, interfacing, limitations and warnings)
- User manual (handling, servicing, re-calibration)

Characterization

The understanding of the achieved data quality will evolve together with refinements of the sensing method and characterization against reference instruments. This is the discipline of metrology.

The status of sensor characterization can be described as a “Data Readiness Level”.

DRL:	Data Readiness Level
0	Invalid data
1	Raw or unscaled data
2	Scaled data
3	Scaled data with defined precision or noise level
4	Scaled data with defined precision and noise levels, but not related to the larger body of scientific knowledge
5	DRL 4 data related to the larger body of scientific knowledge, but with measurement uncertainty too large for data standards
6(X)	Standards-quality data of X % measurement uncertainty

Figure from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5332131/

Different customer groups have different requirements on Data Readiness Level to be able to use a sensor for their objectives. For example, climate research have very high requirements on long-term absolute accuracy of readings to make conclusions on long-term trends. In contrast, finding gas leaks is possible with only coarse indications of relative concentrations.

Cooperation with private companies

Many areas of expertise is necessary to launch a product, and anyone can be forgiven for needing outside help. In general, until phase 5 ("Commercial viability study") is done, an outside company lacks the information necessary to make an informed decision on the commercial value and is therefore more inclined to accept work only as consultant at hourly rate.

After phase 5, the inventor has objective arguments of the monetary value of the intellectual property and stands a much better chance of trading some of that for an investment of time or money to take the project the rest of the way to a sellable product. In such a scenario, it is important to understand the policy of your employer on licensing of intellectual property, non-disclosure agreements, etc.

Sparv Embedded (sparvembedded.com) is an engineering company specializing in developing mobile sensor systems in cooperation with environmental scientists. We welcome comments, discussion and inquiries at anders@sparvembedded.com.