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AN IMPROVED METHOD AND FORECAST FOR THE WORLD-WIDE MARKET GROWTH OF MEMS

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Executive Summary

A forecast based on expert opinions for the twenty-six major markets that have been identified for MEMS shows that there is tremendous variation in future sales levels based on current opinions. In the short run, maximum forecasts diverge by a few hundred percent in each market. Whereas by 2025, the divergence between minimum and maximum forecasts are between one and two orders of magnitude for all applications considered. The forecast for global sales of MEMS ranges between \$600 million and \$31 billion. By 2025 the forecast for global sales of MEMS ranges between \$9 billion and \$360 billion. These figures represent the sum of the minima and maxima of all 26 forecasts. The average forecast for global sales of MEMS in 2003 and 2005 is \$6.7 billion and \$137 billion, respectively.

1.0 Introduction

Market forecasts for twenty-six separate applications in MEMS are obtained through expert opinions. This forecast differs from previous forecasts, because a probability range is offered instead of a median or range. Through the use of a probability space, the maximum amount of information obtainable from an expert forecast is obtained. Forecasts are offered for 2003, 2005, 2010, 2015, 2020, and 2025 for thirteen current applications, thirteen emerging applications, and the overall MEMS market.

2.0 The Challenges in Forecasting MEMS

Forecasts of the market size of MEMS are frequent and differ greatly in their results (see Figure 1). Due to the relative youth of this field, forecasts are based on expert opinions. Past forecasts have been based on either average values of expert opinions (Grace 1990, SPC, 1994, 1999) or ranges of expert opinions (Japanese Micromachine Center, 1999, VDC 2000, Wechsung, 1998). The results of these forecasts differ substantially. This is a result of a number of challenges facing the forecast of MEMS market size which include:

- 1) Most application markets are currently immature, making traditional forecasting methods not applicable.
- 2) Many markets do not yet exist. As a result, forecasts attempt to identify not only the rate of increase in sales, but also the first year of commercialization.
- 3) Different people define MEMS sales differently. Some earlier forecasts consider only the MEMS component of a product, whereas others consider the entire product or product system.
- 4) Pricing and sales of MEMS products can differ depending on whether value pricing, margin-based pricing or forward pricing is used.
- 5) Different forecasts may consider different products, applications and/or industries.
- 6) Forecasts are typically based on the range or average of estimates made by experts. Different groups of experts offer different market sales estimates.

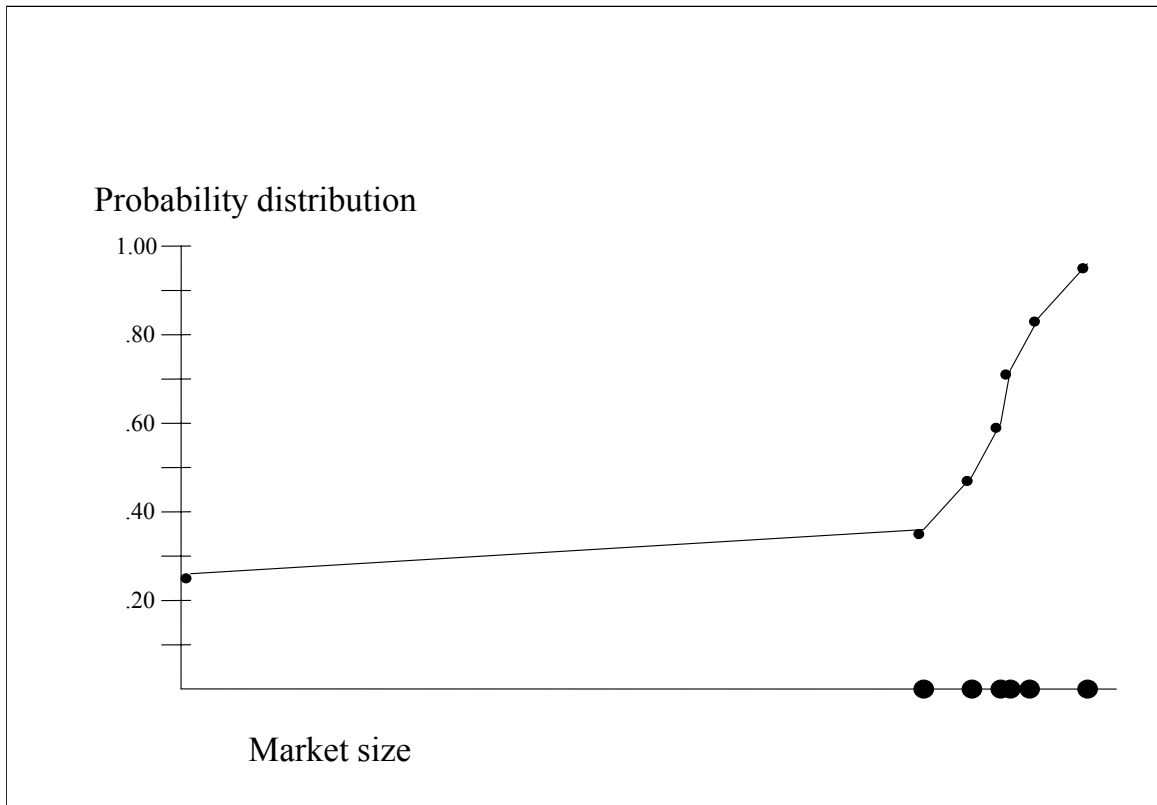


Figure 1. Probability versus Market Size for a Group of Experts in Relative Consensus.

Faced with all these complications, the difficulty in providing forecasts is obvious. Due to the high demand by business and policy makers for insights into what the future may look like, forecasts will always be demanded, whether accurate or not. There are two major problems with the use of a single value (average). The presentation of a single value can mistakenly lead to the impression of precision—when precision does not exist. Furthermore, the use of a single value does not take advantage of all the information that was collected during the interviewing or surveying of the numerous expert opinions during the forecast process. Similarly, the presentation of a range does not take advantage of all the information provided by the pool of experts. The presentation of an upper and lower value does not present the illusion of precision that may be associated with the presentation of an average value. The use of ranges in forecasting is clearly an improvement over the average method. But the range does not offer insight into the distribution of the different expert opinions within the range. To maximize the amount of information from an expert forecast one should take advantage of the information provided by all of the experts. In this paper, we do this by converting expert opinions into a

continuous function that has a minimum value of the lowest forecast and a maximum value of the highest forecast. Such a function is shown in equation 1. It is possible to assign any weights to the predictions offered by the different experts. We assume equal weights since we have no reason to believe that one expert opinion is superior to another.

$$F(V_j) = X_i + (X_{i+1} - X_i) * (V_j - S_i) / (S_{i+1} - S_i) \quad (1)$$

$$S_i = S_{i-1} + W_i \quad (2)$$

Subject to:

$$\sum W_i = 1 \quad (3)$$

$$S_1 = 0 \quad (4)$$

$$S_n = 1 \quad (5)$$

$$0 \leq V_j \leq 1 \quad (6)$$

$$S_i \leq V_j \leq S_{i+1} \quad (7)$$

$$0 \leq W_i \leq 1 \quad (8)$$

where:

i is from 1 to $n-1$

n = the number of expert opinions

X_i = the opinion of expert i , with each expert opinion ordered in increasing magnitude of the prediction—from 1 to n

W_i = the weight given to the opinion of expert i

V_j = a randomly generated number

j = a value from 1 to k and k is the bootstrap size desired for resampling

$F(V_j)$ = the forecast based on the randomly generated value V_j .

Having outlined the alternative forecasting method and the rationale for using a different method for forecasting, the method used in the forecast is described.

3.0 Forecast Method

Nine experts agreed to provide their predictions of world sales for twenty-six submarkets. These submarkets are per the recommendations of Nexus (Wechsung, 1998) and are summarized in Table 1. Each expert provided predictions of the world sales for each application in 2003, 2005, 2010, 2015, 2020, and 2025. (If the participant lacked expertise in a specific area they did

not provide a forecast.) The predictions for each application and time period were ranked in ascending order and converted to a uniform function. (The prediction of each expert was considered as having an equal weight to all other forecasts.) The lowest prediction was treated as the zero point of the function. The highest prediction was considered as the highest possible value. The remaining forecasts fall between the highest and lowest at equal intervals (see Figure 2). One thousand forecast simulations were generated for sufficient forecast estimations with confidence ranges (Hall 1986; Booth and Sarkar 1998). This was achieved by generating one thousand different random numbers for each application and year of prediction. The one thousand random numbers associated with each application and year was transformed into predictions using the functions based on the expert opinions. The average of these predictions is calculated for each of the twenty-six markets along with their associated confidence ranges (see Figures 3 to 28). The results from the twenty-six applications are used to generate a forecast for the global sales of MEMS products shown in Figure 28.

Table 1. Applications Considered in Market Sales Forecasts

Current applications	Emerging applications
Accelerometers	Anti-collision sensors
Chemical sensors	Coil-on-a-chip
Gyroscopes	Drug-delivery systems
Hard disk-drive heads	Electronic noses
Hearing aids	Inclinometers
In-vitro diagnostics	Injection nozzles
Infrared images	Lab-on-a-chip
Magneto-resistive sensors	Magneto-optical heads
Micro spectrometers	Micromotors
Optical displays	Micro relays
Pacemakers	Optical switches
Pressure sensors	Projection valves
Printheads	RF devices

4.0 Interpreting the Forecast Charts

Each forecast consists of five lines. The middle line is the average value of all of the forecasts. This is the value that is offered in traditional forecasts of MEMS. The lines above and below the middle line indicate the forecasts values one standard deviation above and below the average. In practical terms, the forecast values at these two lines indicate the range that the sales value should fall 68% of the time, based on the expert opinions. If the experts are in close

agreement, the difference between these two lines (+ and – one standard deviation) and the average line will be very small. As the experts’ opinions vary more, the distance between these lines increases (information that was lacking in earlier forecasts of MEMS.) Finally, the two outer lines on each graph, represents plus and minus two standard deviations from the mean. This is the range that the actual worldwide sales will be within 95% of the time, based on expert opinion. The high uncertainties associated with forecasting MEMS makes offering a single-point prediction misleading to many a people. Consequently, ranges of forecast values with associated probability are more informative. For ease of interpretation, the data presented has been summarized in Table 2 (shown after Figure 28).

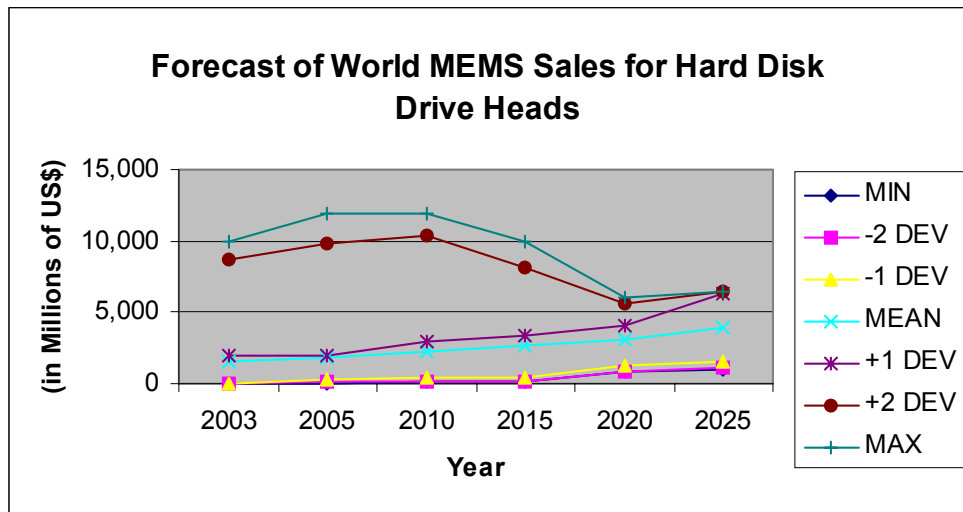


Figure 2. World MEMS Sales for Hard Disk-drive Heads.

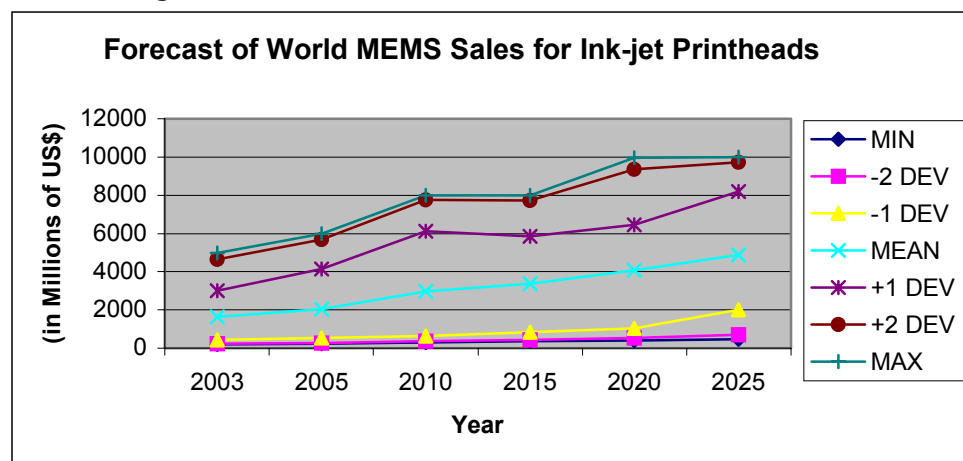


Figure 3. World MEMS Sales for Ink-jet Printheads.

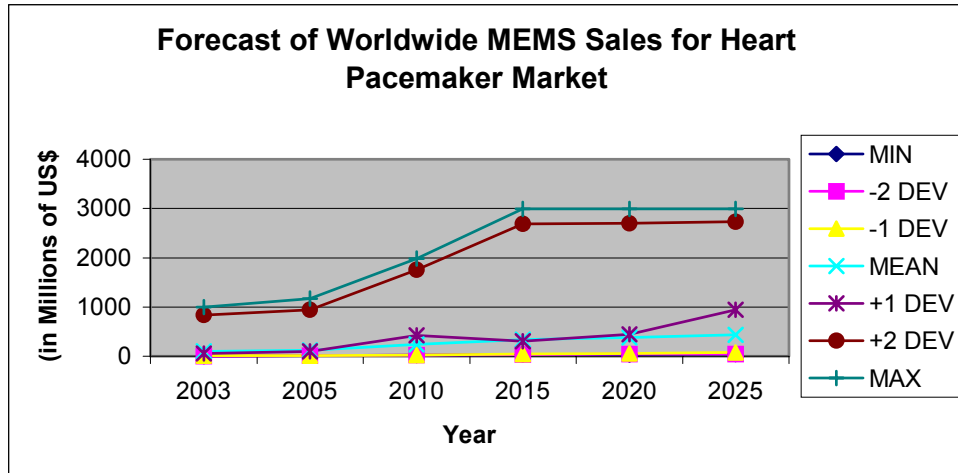


Figure 4. World MEMS Sales for Heart Pacemakers.

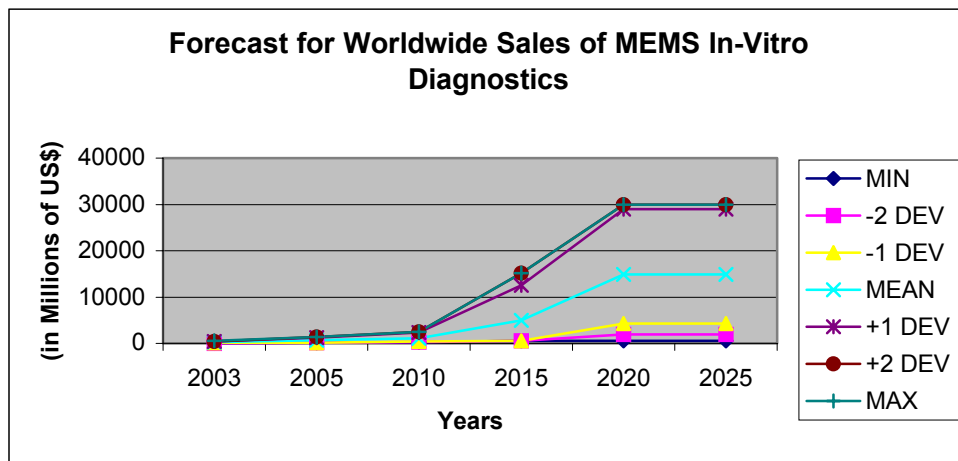


Figure 5. World MEMS Sales for In-vitro Diagnostics.

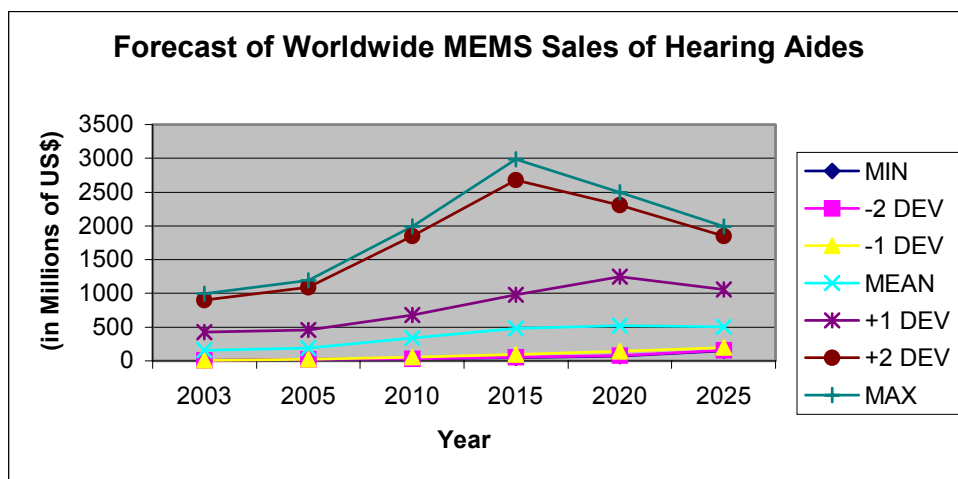


Figure 6. World MEMS Sales of Hearing Aids.

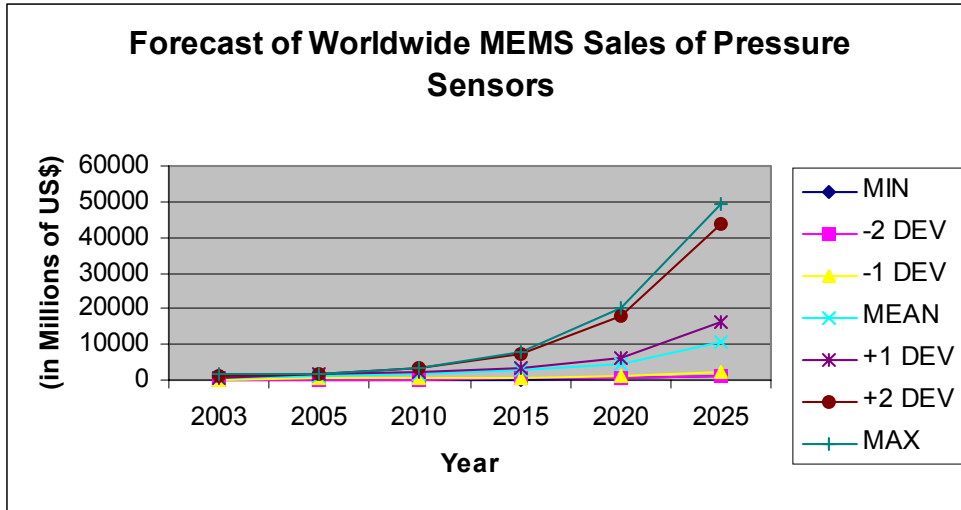


Figure 7. World MEMS Sales of Pressure Sensors.

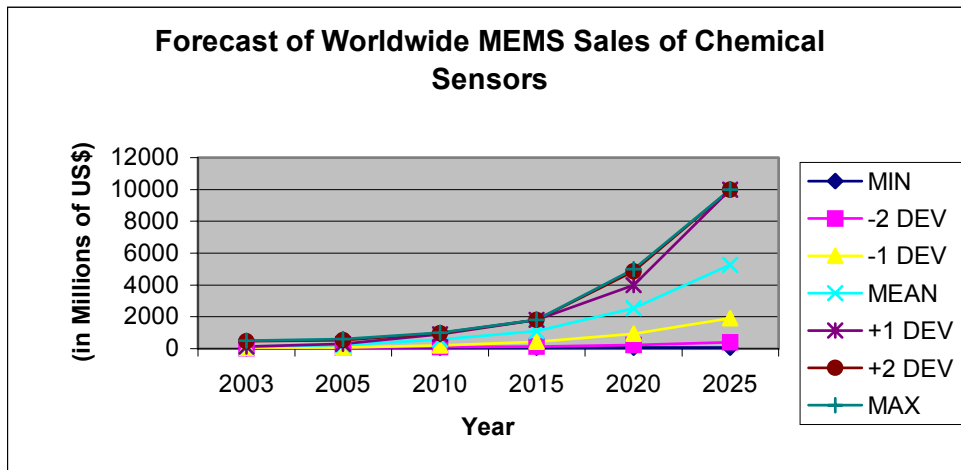


Figure 8. World MEMS Sales of Chemical Sensors.

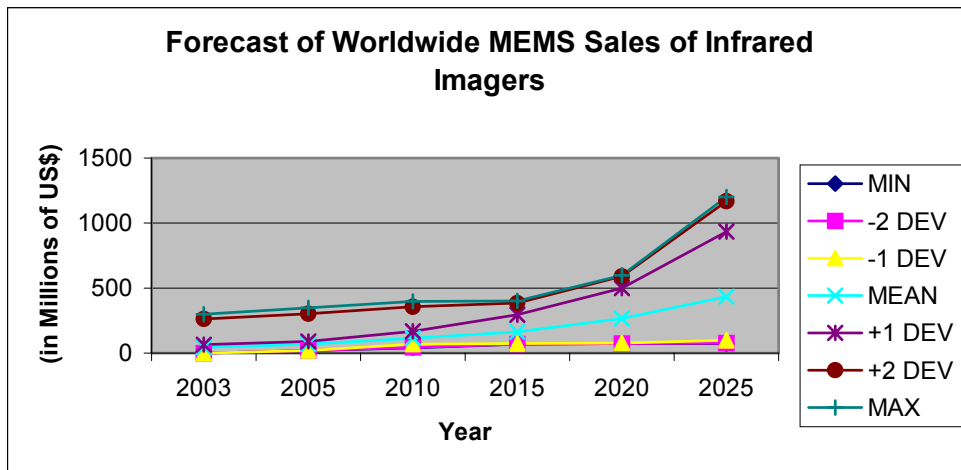


Figure 9. World MEMS Sales of Infrared Imagers.

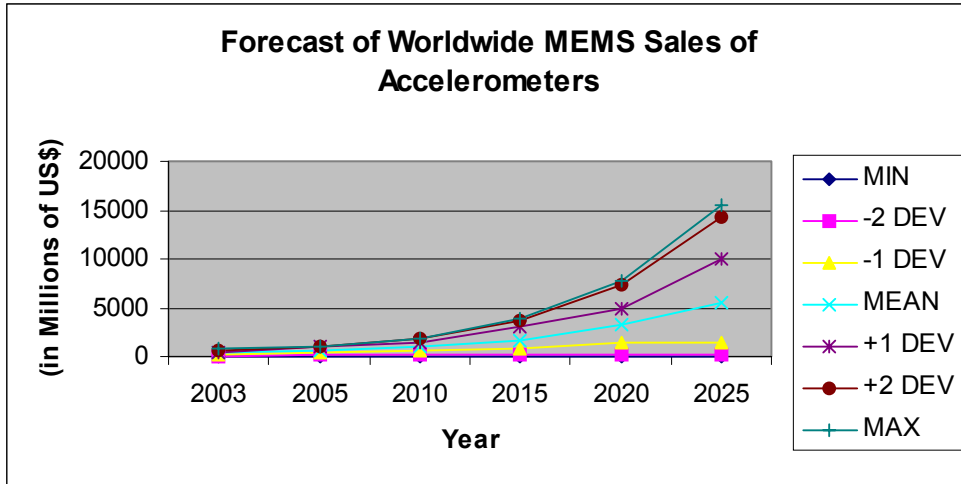


Figure 10. World MEMS Sales of Accelerometers.

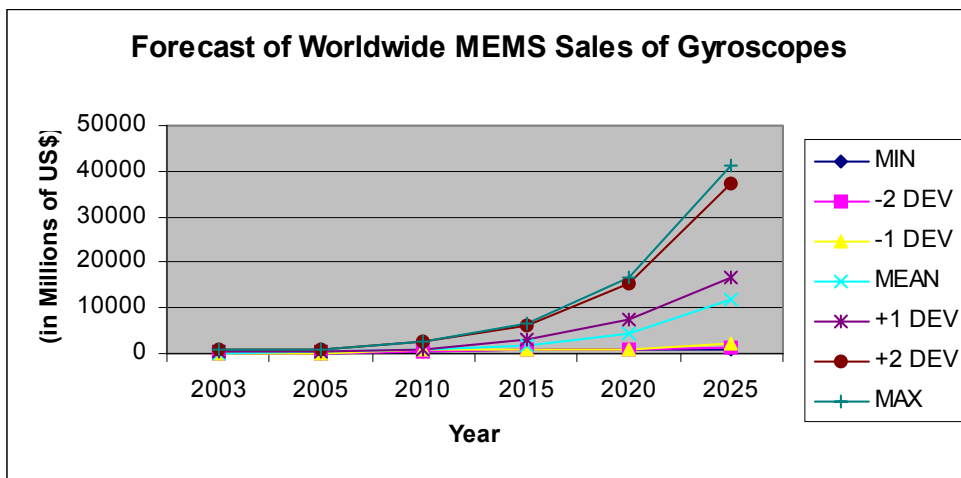


Figure 11. World MEMS Sales of Gyroscopes.

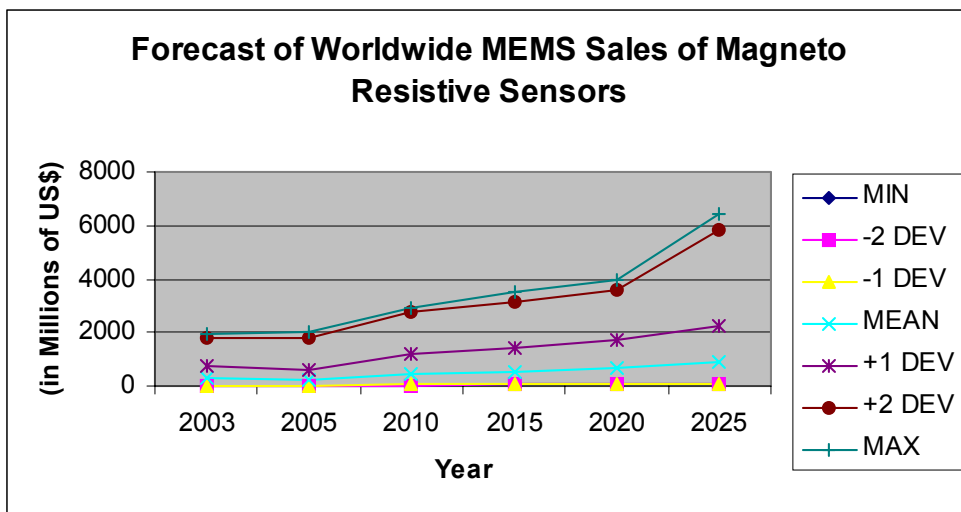


Figure 12. World MEMS Sales of Magneto-resistive Sensors.

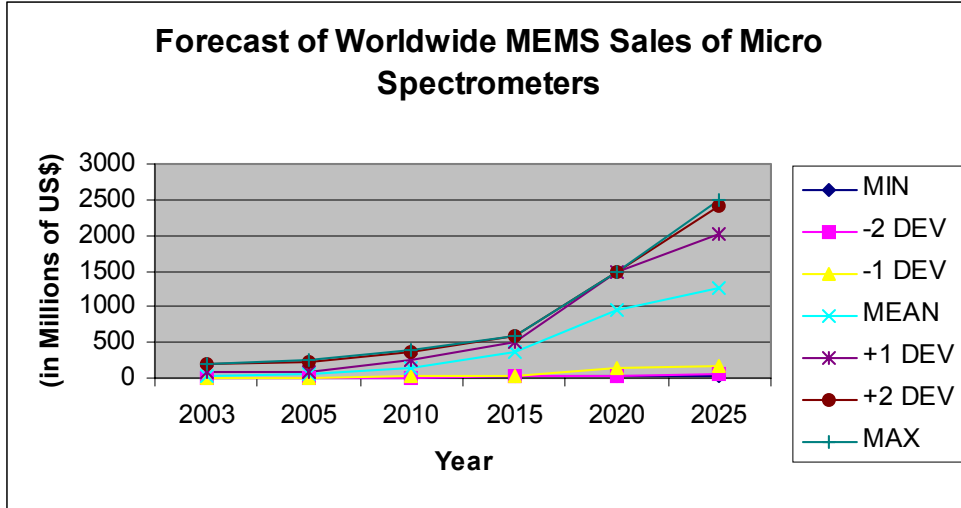


Figure 13. World MEMS Sales of Micro Spectrometers.

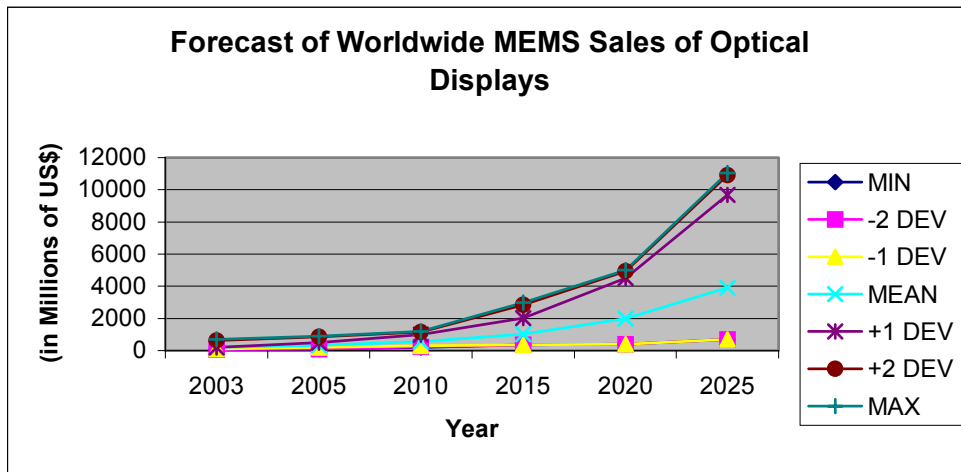


Figure 14. World MEMS Sales of Optical Displays.

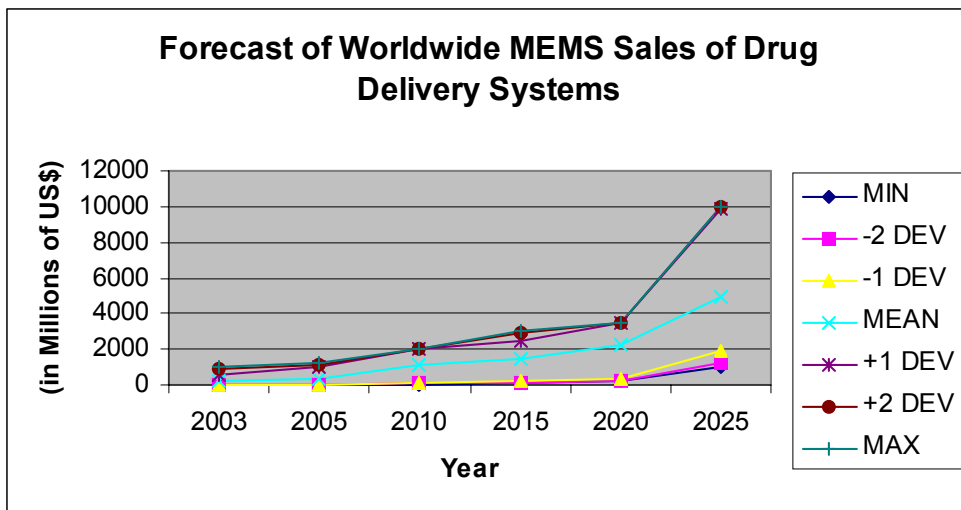


Figure 15. World MEMS Sales of Drug-delivery Systems.

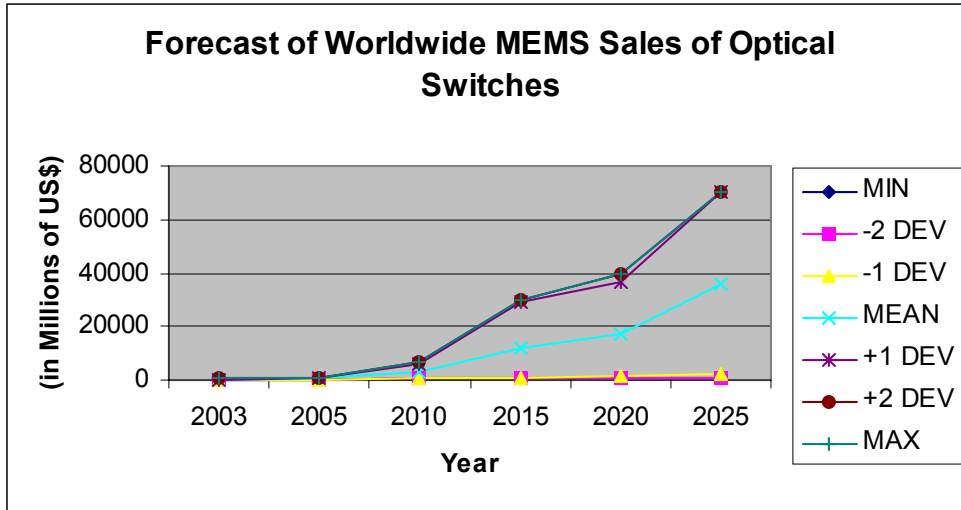


Figure 16. World MEMS Sales of Optical Switches.

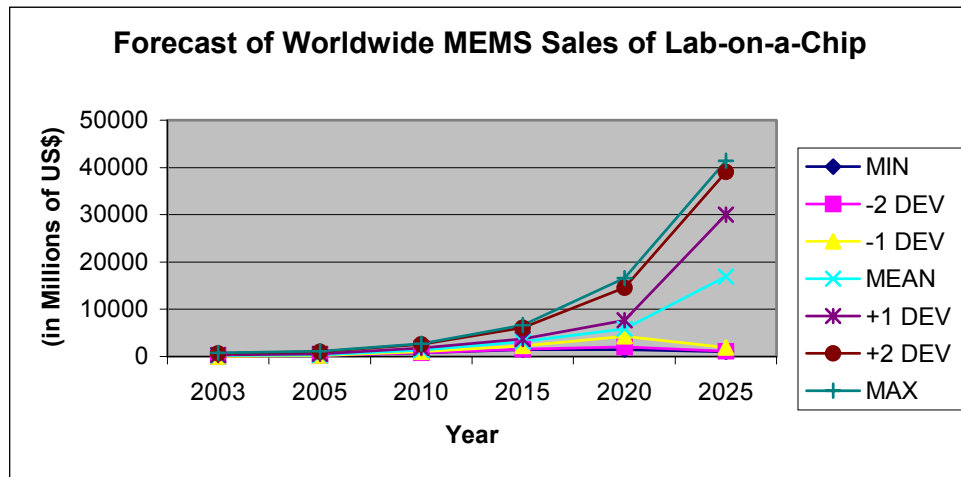


Figure 17. World MEMS Sales of Lab-on-a-chip.

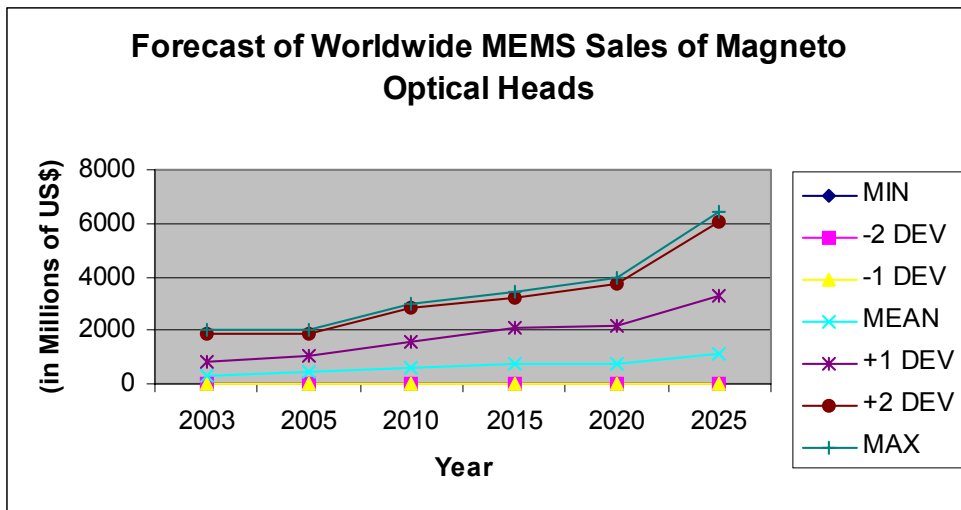


Figure 18. World MEMS Sales of Magneto-optical Heads.

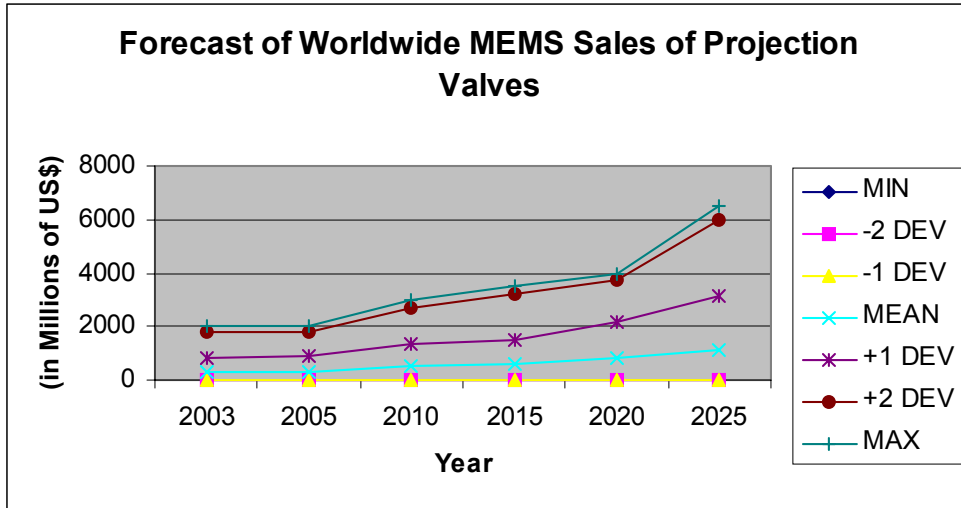


Figure 19. World MEMS Sales of Production Valves.

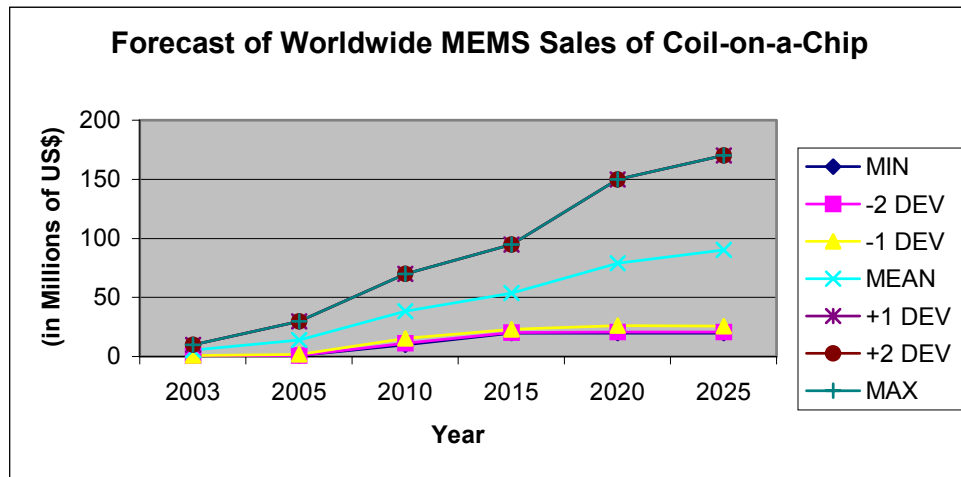


Figure 20. World MEMS Sales of Coil-on-a-chip.

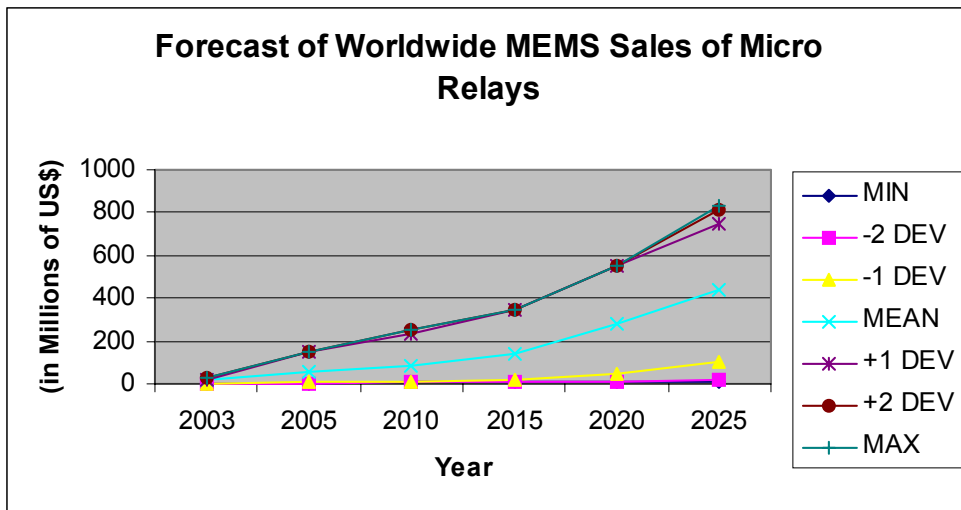


Figure 21. World MEMS Sales of Micro relays.

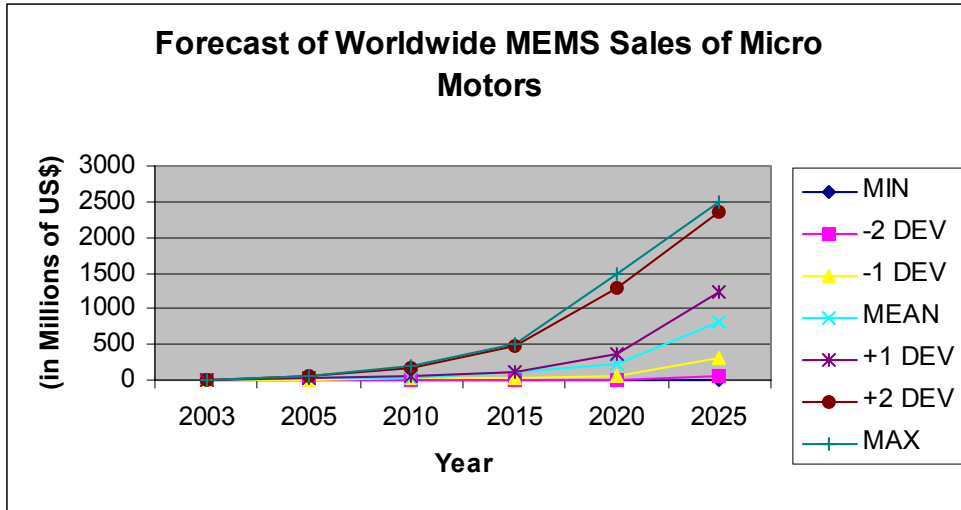


Figure 22. World MEMS Sales of Micro Motors.

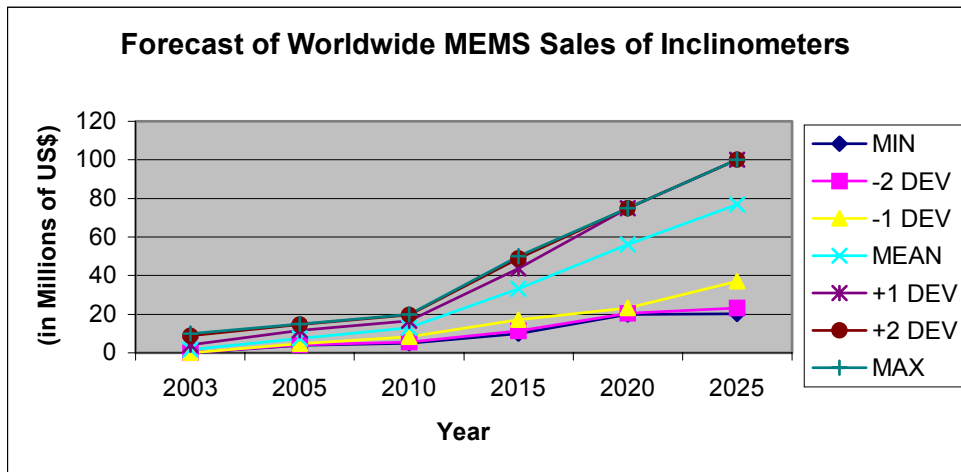


Figure 23. World MEMS Sales of Inclinometers.

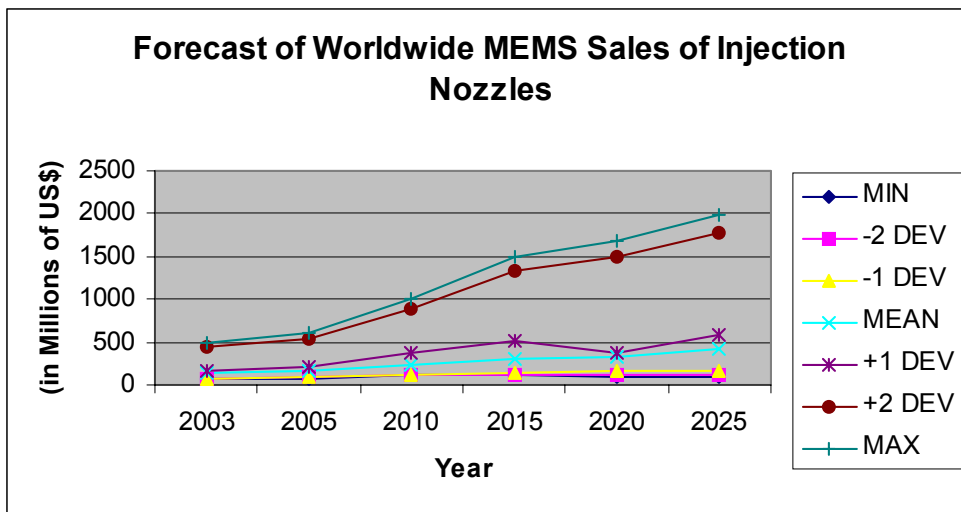


Figure 24. World MEMS Sales of Injection Nozzles.

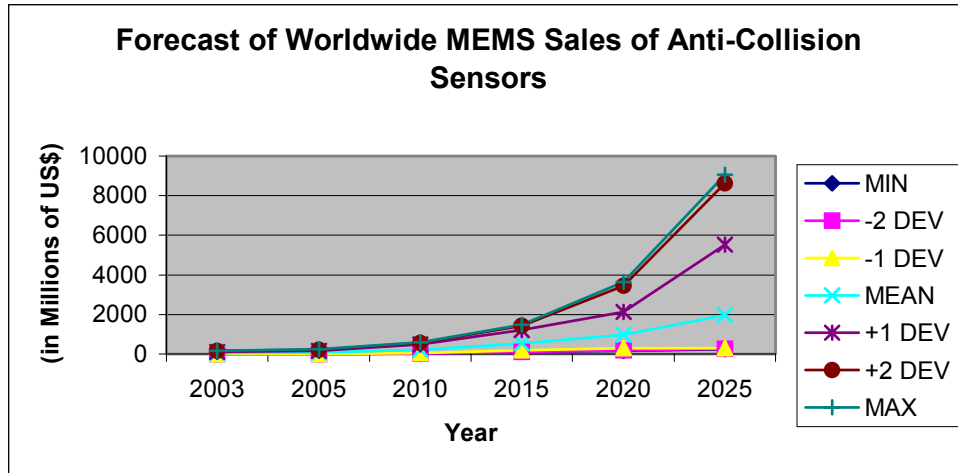


Figure 25. World MEMS Sales of Anti-collision Sensors.

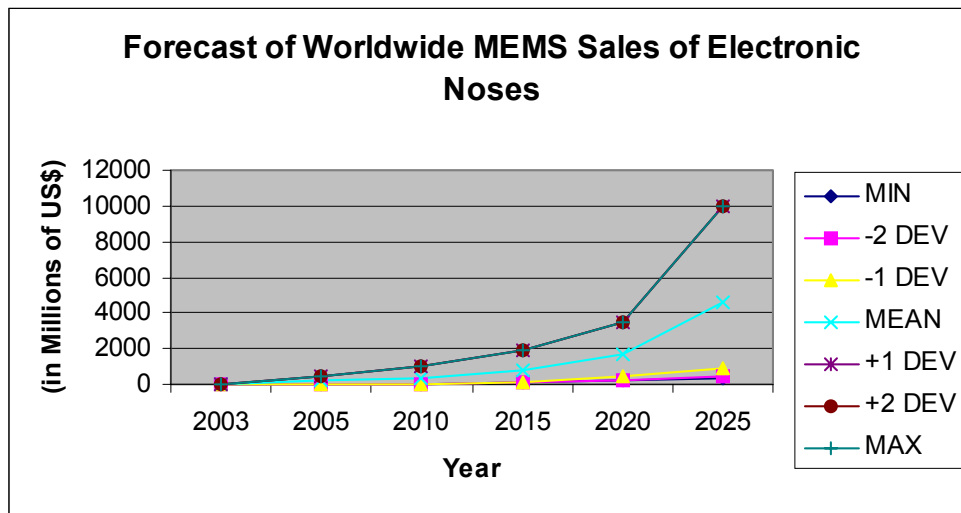


Figure 26. World MEMS Sales of Electronic Noses.

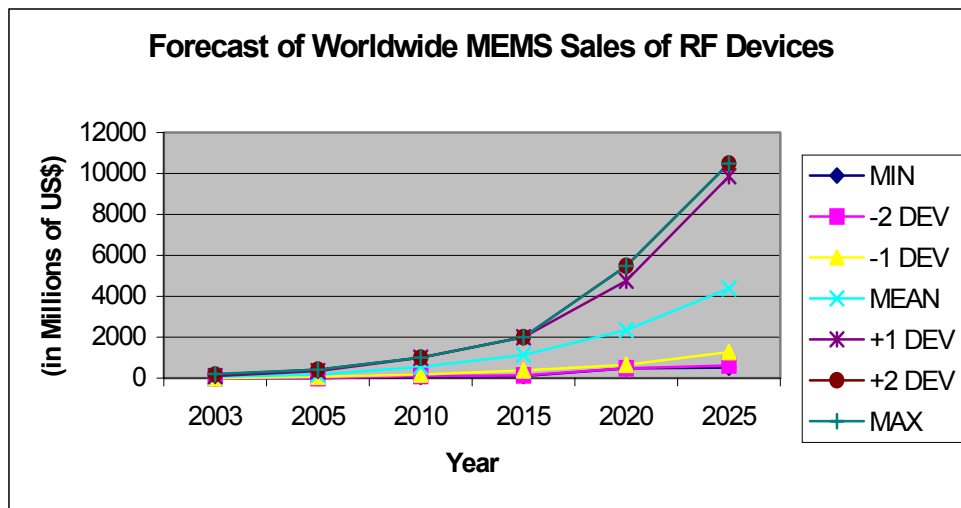


Figure 27. World MEMS Sales of RF Devices.

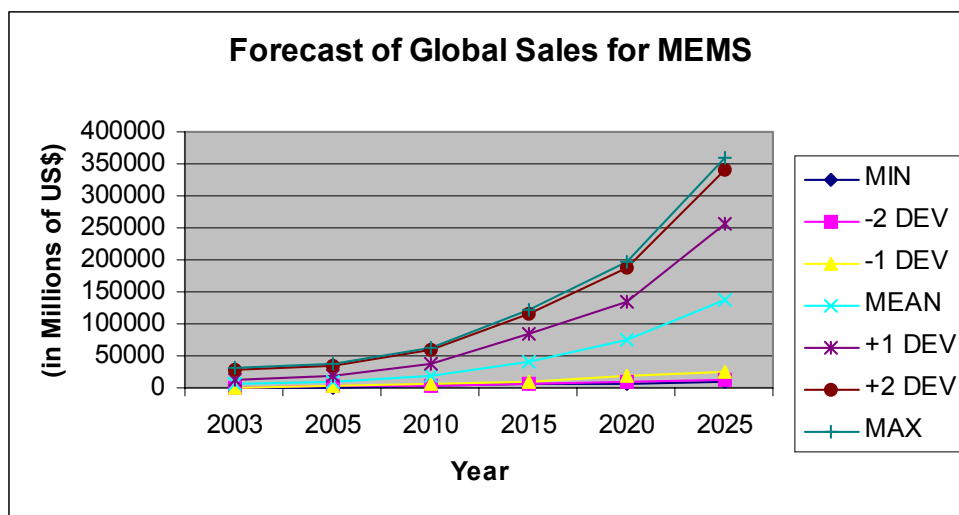


Figure 28. Global MEMS Sales.

Table 2. Prediction of Global MEMS Marketplace for the 26 Application Areas (\$billions)

Year	2003	2005	2010	2015	2020	2025
Minimum	0.67	1.25	3.43	5.37	7.13	8.88
-2 deviations	0.78	1.59	3.80	6.06	9.99	12.25
-1 deviation	1.30	2.86	5.89	9.94	19.91	26.08
Mean	6.69	10.30	20.07	42.09	74.50	137.03
+1 deviation	12.06	18.19	37.31	83.93	135.77	257.40
+2 deviations	28.49	35.20	58.37	114.95	187.86	341.91
Maximum	31.49	38.92	61.99	121.47	196.52	358.06

5.0 Conclusions

The forecasts indicate that the anticipated market sizes, growth rates, and onset of growth are very different for different applications of MEMS. Consequently, it is necessary to consider these applications separately and sum them up to obtain an overall forecast. Given the detail in this information, it becomes easier to understand the significance of any incorrect assumptions and adjust overall forecasts in response to the changes in specific markets. The high uncertainty depicted by the confidence ranges indicates that frequent updates of forecasts are necessary. Without continued monitoring, it is likely that MEMS product applications will become either supply constrained or awash in over-capacity. Continued forecasts can add great value here, since neither of these situations is desirable.

6.0 References

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