Magnesium substitution in the automotive industry has steadily increased over the last decade, in parts such as valve covers, instrument panels, steering wheels, steering wheel armatures, and seat bases. North American auto applications have risen at a rate of 6 to 12% per year for the last 12 years, culminating in a 2002 model average of 4.1 kg per vehicle. Some high-end models have much greater magnesium content. For example, the 2003 Dodge Viper is slated to contain over 20 kg, mostly due to the one-piece instrument panel that has been incorporated into the design (Fig. 1). The rate of substitution in Europe, while initially slower, has escalated to an increase of 15% by weight per year.

Developing supplier relationships is another strong indicator of this trend. Well-known relationships include Ford Motor Co. and Australian Magnesium Corporation; General Motors Corp. and Norsk Hydro; and Volkswagen and Dead Sea Magnesium.

To quantify trends such as this, a mathematical approach known as Technical Cost Modeling (TCM) has been developed at IBIS. This unique tool is useful for comparing alternative manufacturing technologies. The technique is an extension of conventional process modeling, with particular concentration on the cost implications of material and process variables, given changing economic scenarios.

This article shows how this technique can be applied to the cost of magnesium parts, then makes a comparison with parts made of aluminum and polymers.

Understanding costs
The goal of TCM is to understand product costs, and to show how these are likely to vary with changes to the product and process. Specifically, this includes the breakdown of the process into its constituent operations and elements (Fig. 2).

The focus of TCM can be limited to direct manufacturing, or it can be expanded to account for the entire product lifecycle. Manufacturing typically covers fabrication, assembly, and finishing. The complete lifecycle might also include raw material extraction and processing; product installation, transportation, storage, operation, maintenance, and repair; and reuse, recycling, and disposal.

To evaluate magnesium auto parts, this methodology was implemented for a comparative analysis of automotive valve covers, which present a promising opportunity for magnesium. In fact, Ford recently switched all of its Triton engine valve covers from Nylon 6-6 to magnesium, affecting an estimated 800,000 vehicles.

The materials selected for the analysis included secondary 380 aluminum, AZ91 magnesium, 33% glass loaded nylon 6-6, 20% glass loaded polyester (BMC695), and 33% glass vinyl ester (SMC). The prices quoted are market snapshots, and it should be noted that material grades and compositions are varied for this particular application.

Aluminum and magnesium were initially modeled with the same wall thickness. However, benefits based on the thin wall capability of magnesium were also analyzed, as this is one of its primary advantages. Cycle times for magnesium are also lower than aluminum because of its rapid solidification properties and shorter dwell times. In addition, magnesium tool life is two to three times longer than aluminum, a result of lower melting temperatures and less corrosive activity. Machining and tooling costs for all materials are representative of the press size and die capacity required for a part of this geometry.
Figure 3 shows an elemental breakdown of cost for the five manufacturing scenarios. Magnesium proves to be the most expensive option, followed closely by aluminum. BMC is the most economical alternative, slightly cheaper than SMC. It is interesting to note that 54% of magnesium valve cover cost is in material. Conversely, only 58% of the cost for the BMC cover can be attributed to material.

Cost factors

To address specific cost factors, a sensitivity analysis was run on the magnesium cover as shown in Fig. 4. A multiplier is shown for five parameters: tooling, equipment, material price, runner weight, and wall thickness. The sensitivity analysis explored the economic impact of iteratively varying one of the parameters at a time, while holding the others constant at a baseline value.

- **Material price**: Reductions in material price and wall thickness had the greatest effect on manufacturing cost.
- **Runner parameter**: The runner parameter refers to development of a “hot runner” process, in which the amount of scrap would be reduced. However, the reduced scrap did not have much effect on overall cost, because the incumbent cold runner configuration already had a high scrap rework rate of 80%. Without this rework, the cost penalties for a system with runners would be much more severe, and the benefits of developing a “hot runner” configuration much more significant.
- **Tooling**: Reductions in tooling and equipment investment did not have a significant effect on overall manufacturing cost.

These results reinforce the message that material cost is the main disadvantage for magnesium.

Wall and weight reduction

- **Wall thickness**: The effect of wall reduction was analyzed for aluminum, and Fig. 5 details the consequent cost reductions for magnesium and aluminum. Aluminum wall reduction ceased at 3.5 mm, which is thought to be a bottom limit for this size part. If aluminum is manufactured with a 3.5 mm thickness, the break-even thickness for magnesium is 3.1 mm. However, to compete with a nylon 6-6 cover, magnesium wall thickness needs to reach 2.9 mm. Neither aluminum nor magnesium has the potential to compete with SMC or BMC based on a feasible wall-thickness reduction.

Two smaller geometries were studied to explore the economic position of magnesium, Fig. 6. The smaller cover measured 17 x 7 in, and the medium cover measured 28 x 6 in. Also shown on this graph is a magnesium part with a 3.6 mm wall. Magnesium is in the least unfavorable position at the smallest geometry, although at no point is it competitive with the thermoset materials, SMC and
analysis of four parameters: mass, coefficient of drag, engine displacement, and horsepower. A database of vehicle information included production models and ultra-light concepts. This analysis demonstrates that for every 10 kg of mass reduction, fuel economy is increased by one-tenth of a mile per gallon.

While seemingly insignificant in terms of cost of ownership, one-tenth of a mpg can be a critical factor. If a vehicle were one-tenth of a mpg off the CAFE requirement, the cost would be $5.50 per vehicle sold in that model year. To translate this cost into dollars per kg, based on the relationship discussed, the penalty is $0.55 per kg per vehicle for the OEM. Cost of ownership refers only to fuel cost over the vehicle lifetime, and does not consider additional scheduled maintenance.

However, the most interesting figure is the price that car companies are willing to pay for that weight reduction. Ford is believed to pay $3.30 per kg, but an industry-wide value is not known. In some instances, this willingness to pay may be sharply increased if modifications on a low-volume model can prevent a fleet-wide penalty.

Cost penalties for magnesium substitution depend on the application. Based on this analysis, cost of weight savings over aluminum varied between $0.20 and $0.90 per kilogram, depending on wall thickness and geometry. The relative cost of magnesium weight savings over steel was also explored. Table 3 references prior analyses at IBIS Associates. The door information was provided through Wagon Automotive.

While some magnesium applications offer so many benefits the company is willing to pay extra, a cheaper material is almost always available. For example, aluminum is consistently cheaper than magnesium for the same application. Furthermore, price fluctuations and uncertain supplies have resulted in a price position that, on a volumetric basis, does not compete with aluminum.

The break-even point for the pricing ratio is roughly 1.7, meaning that the price of magnesium can be 1.7 times greater than aluminum before the cost of weight savings is favorable. Currently, this ratio is 2.2.

Thermoplastics and thermosets are also proven lighter and cheaper alternatives, for applications without performance constraints.

**Trend vs. fat**

The question remains: What distinguishes a trend from a fat? Trends are evaluated on their ability to compete on the bases of cost and performance. In the automotive industry, cost and performance are the driving factors for change. Figure 8 portrays a 3 x 3 matrix that can help to qualify these factors.

**Ideally, companies strive for the lowest cost,**

---

**Table 1 — Model inputs for magnesium valve covers**

<table>
<thead>
<tr>
<th>Input</th>
<th>Cast Al</th>
<th>Cast Mg</th>
<th>Nylon 6,6</th>
<th>I/C BMC</th>
<th>O/M SMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>380 sec</td>
<td>AZ91</td>
<td>33% glass</td>
<td>20% glass</td>
<td>30% glass</td>
</tr>
<tr>
<td>Wall thickness, mm.</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2.85</td>
<td>2.13</td>
</tr>
<tr>
<td>Part weigh, kg</td>
<td>5.4</td>
<td>3.5</td>
<td>2.1</td>
<td>2</td>
<td>1.8</td>
</tr>
<tr>
<td>Material price, $/kg</td>
<td>1.45</td>
<td>2.86</td>
<td>3.74</td>
<td>2.09</td>
<td>2.21</td>
</tr>
<tr>
<td>Cycle time, sec</td>
<td>30</td>
<td>23</td>
<td>47</td>
<td>70</td>
<td>71</td>
</tr>
<tr>
<td>Machine cost, $/machine</td>
<td>450</td>
<td>450</td>
<td>1200</td>
<td>700</td>
<td>838,000</td>
</tr>
<tr>
<td>Operators / Mach</td>
<td>2</td>
<td>2</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Tool cavities/tool</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Tool cost/ $/tool</td>
<td>63,902</td>
<td>60,836</td>
<td>19,256</td>
<td>239,349</td>
<td>375,490</td>
</tr>
<tr>
<td>Tool life, parts/tool</td>
<td>150</td>
<td>300</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>

**Table 2 — Cost of magnesium weight savings over steel**

<table>
<thead>
<tr>
<th>Part</th>
<th>Mass of steel, kg</th>
<th>Mass of magnesium, kg</th>
<th>Cost of steel, $</th>
<th>Cost of magnesium, $</th>
<th>Weight savings, $/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>I/P support</td>
<td>7.3</td>
<td>6.3</td>
<td>30</td>
<td>35</td>
<td>5.51</td>
</tr>
<tr>
<td>Wheel</td>
<td>16.6</td>
<td>5.3</td>
<td>15.65</td>
<td>35.30</td>
<td>1.73</td>
</tr>
<tr>
<td>Door</td>
<td>20</td>
<td>10</td>
<td>50.69</td>
<td>96.77</td>
<td>4.61</td>
</tr>
</tbody>
</table>

**BMC. Why then, should magnesium even be considered for this application?**

- **Part weight:** Weight reduction is the primary driving force for material substitution in the automotive industry. Nearly all of the existing magnesium applications, including instrument panels, steering wheel assemblies, seat components, and wheels were created as a means for reducing vehicle mass. Thus far, this reduction has been burdened with a substantial cost penalty. To justify this cost, resultant weight savings must improve overall vehicle performance.

Figure 7 shows the relationship between weight savings, fuel economy, and cost of ownership. Average vehicle life was considered to be 145,000 miles, and the cost of gasoline was set at $1.23 per gallon. Similar to fuel economy, weight saving does not have a substantial effect on fuel cost, varying by $355 over a 1,500 kg weight differential. Fuel economy was calculated by the following equation:

\[
\text{Fuel economy, mpg} = \frac{(4410 \times (\text{vehicle mass, kg})^{-0.619}) \times [\text{drag coefficient} \times (\text{width, m}) \times (\text{height, m})]^{-0.257} \times [\text{engine displacement, L}]^{-0.29} \times [\text{engine horsepower, hp}]^{-0.17}}{}
\]

This equation was derived through a regression...
highest performing technology. This figure shows the scalar vectors that quantify a technology’s position. It also portrays how cost and performance are multidimensional qualities that can be affected on many levels. For example, performance is a function of fuel economy, handling, versatility, safety, aesthetics, and consumer preference, among others.

Economic basis
On a purely economic basis, magnesium substitution is not defensible. Therefore, magnesium substitution is not based entirely on volumetric weight reductions. Aside from its low density, magnesium has the highest strength-to-mass ratio of all the metals in the automobile. It also has a high damping capacity, low thermal expansion coefficient, and good electrical conductivity. The ability to utilize multiple performance attributes while achieving substantial weight savings speaks favorably for the future of magnesium.

Harnessing the value-added properties of magnesium will help offset the cost penalty in parts such as valve covers. In this case, magnesium is chosen over nylon 6-6 not because of its mass or cost, but for NVH reduction and sealing capacity. These perceived benefits outweigh the additional costs, at least in this case.

Consumer preference can also outweigh economic position. Aluminum wheels have successfully captured 53% of the light wheel market, even though they are more expensive than steel, and in some cases even heavier.

Future of magnesium
The future of magnesium in the automotive industry will rest heavily on two factors. First, a “champion application” must be uncovered. So far, no applications have been developed that harness enough performance attributes for it to be widely adopted.

Second, suppliers and manufacturers must reduce its cost. In fact, magnesium pricing is expected to level off, and even has the potential to decline.

Manufacturers are doing their part, implementing novel modifications to established operations. Nevertheless, until the price of magnesium drops closer to that of aluminum, it will be difficult for any application to be widely accepted.

The magnesium movement has been waverling between trend and fad for the last twenty years, at times gaining momentum, and at times burdened by its own high price. All this while, its performance attributes have been widely touted and novel applications have continued to emerge. To term this development as a “trend” connotes an accepted change, the ability to challenge the current king. However, in the automotive industry, cost is king, and magnesium is a long way from winning that battle.