Market Progress Evaluation Report

MAGNADRIVE, NO. 2

prepared by

Quantec

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Final Report

Second Market Progress Evaluation Report for the MagnaDrive Adjustable Speed Drive Phase II

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Executive Summary

Introduction

This Market Progress Evaluation Report (MPER) is the second of three progress reports that will be prepared by the Quantec team over the course of this assignment. It covers research and analysis conducted between November 2000 and October 2001.[1]

The Northwest Energy Efficiency Alliance (Alliance) and the MagnaDrive Corporation (MagnaDrive) have formed a public/private partnership to help commercialize the MagnaDrive Adjustable Speed Drive (ASD). The MagnaDrive ASD is an innovative speed-control device that transmits torque through an air gap by using powerful permanent magnets. The MagnaDrive Corporation and the Alliance have been working together since May 1999.

In general, MagnaDrive ASDs have lower life cycle costs, faster payback, and higher internal rate of returns (IRRs) compared to both variable frequency drives (VFDs) and the base-motor case. This holds for all applications (pump or fan) and motor size, and new or retrofit.

Phase 1 of the project involved a number of tasks, including the testing and comparison of the ASD to VFD, control valves, and dampers at Oregon State University's Motor Systems Resource Facility (MSRF); development of case studies of ASD installations at four industrial sites; and a market assessment study.

The findings from Phase 1 concluded that the MagnaDrive affords the market a strong technology for speed-control applications with its simple, non-electronic, ASD that provides, on average, two-thirds of the energy savings of a comparable VFD and can be used in many applications where a VFD is not cost-effective. The MagnaDrive ASD also offers a number of benefits that will support its growth in the speed-control market – potentially lower costs in larger motor sizes, mechanical operating advantages, the avoidance of electrical problems and the offer of an elegant speed-control solution for retrofitting the many existing non-inverter duty motors.

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[1] The first MPER covered the period from August 15 through November 15, 2000. See "Market Progress Evaluation Report MagnaDrive, No.1," prepared by Quantec with Market Link Strategies, Schiller Associates, and XENERGY, report #E01-080, May 2001.

Three key market barriers were identified in Phase 1 that MagnaDrive is diligently working to overcome:

1. Lack of in-field performance data
2. Lack of knowledge in the marketplace about the ASD as a product and technology
3. Lack of brand recognition in the marketplace of both the MagnaDrive ASD and the corporation

The overall findings from Phase 1 have led the Alliance to fund a second phase research effort. The primary goals of Phase 2 are as follows:

➜ Increase sales in the markets pursued in Phase 1 (pumps, fans, and blowers; pulp and paper; water/wastewater treatment; and HVAC)

➜ Expand the ASD into new target markets (larger motors 500 HP to 1000+ HP, medium- and high-voltage equipment, and irrigation)

Marketing and Sales Update

MagnaDrive developed an aggressive marketing plan for 2001 that targeted water/wastewater, pulp and paper, HVAC, and irrigation applications for the MagnaDrive ASD. This marketing plan addresses the key recommendations in the first MPER, as it focuses on lead generation, trade show participation, sales tools for direct and channel marketing partners, and third-party endorsements. MagnaDrive is also actively pursuing relationships with utility commercial and industrial conservation program managers.

Figure ES-1 shows that more than half of the MagnaDrive sales have been in the water/wastewater industry, far more than any other single industry. In addition, the majority of the applications have been for pumps (72%) (Figure ES-2).

Figure ES-1
Industry Distribution of MagnaDrive Sales

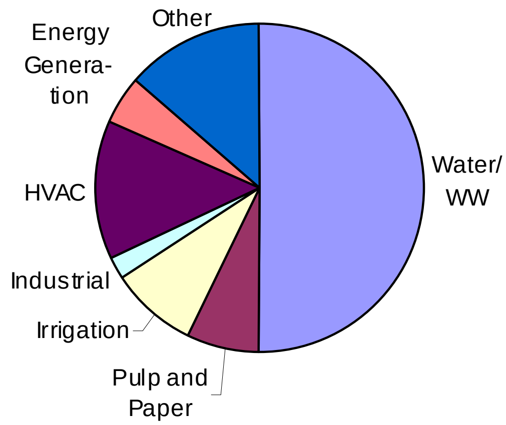
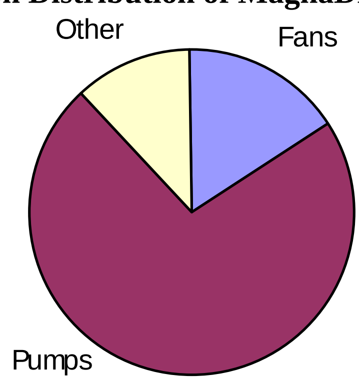


Figure ES-2
Application Distribution of MagnaDrive Sales



Almost 80% of MagnaDrive sales have been to customers served by a Northwest utility. Installations were evenly distributed between medium (100 HP to about 500 HP) and small (under 100 HP) motors.

Alliance Phase II funding is also targeted to the expansion of the MagnaDrive ASD into two specific target markets: (1) large motors (500 HP to 1000+ HP), and (2) the irrigation market. In January 2001, MagnaDrive received a grant from the Department of Energy as part of the National Industrial Competitiveness through Energy, Environment, and Economics (NICE[3]) program. The $500,000 award is for installations of four high horsepower (500 HP to 1500 HP) MagnaDrive ASDs in industrial applications and will augment Alliance Phase 2 resources. These large horsepower applications are still in the design phase, so there is nothing to report on either a technical or marketing front at this time.

MagnaDrive has pursued irrigation case studies, and one is now underway. However, the regional energy crisis that occurred Winter 2000-01 forced many Northwest utilities to pay irrigators not to pump, significantly complicating the irrigation case study effort. As with the high horsepower applications, there is nothing to report at this time.

Interviews with Engineering Consultants

In an effort to better understand how engineering consultants view MagnaDrive in relation to other speed-control devices, Quantec interviewed five consultants that attended a MagnaDrive demonstration and were familiar with the technology.

Some of the consultants worked at large, national consulting firms, while others worked at smaller, regional firms. The detailed responses provide valuable qualitative insights into the consulting engineers' perspectives about MagnaDrive's role in the speed-control market.

Findings from the Interviews

- ***The engineers generally do not believe VFDs have higher maintenance and operations (O&M) costs than regular motors***. All five engineers felt comfortable recommending VFDs for the applications where they are needed: they did not have any reservations about costly O&M expenses for VFDs.
- ***They have not recommended MagnaDrive ASDs because of the uncertainty associated with a new product***. All of the respondents pointed out the uncertainty of recommending a new product to their clients.
- ***Some engineers are not taking the time to fully investigate the pros and cons of the MagnaDrive ASD***. In addition to having standard sets of recommendations, respondents are not comparing their current favorite products with MagnaDrive.
- ***Some clients prefer specifications that can be competitively bid***. MagnaDrive, as the only producer of the MagnaDrive ASD, might be viewed as a sole-source recommendation.

Recommendations from the Interviews

- ***MagnaDrive should collect maintenance data from each of the current installations to build the needed body of knowledge and educate the engineering community as data becomes available.*** Until then, MagnaDrive should not over-emphasize the O&M savings from the ASD.
- ***MagnaDrive needs to continually remind decision-makers about its technology***. Accordingly, MagnaDrive should maximize the number of mailings, phone calls, and visits to the appropriate decision-makers.
- ***MagnaDrive needs to get clients asking for the ASD in the specifications and supply more case studies to allay early adopter fears***. MagnaDrive must continue to educate not only the consultants but also the decision-makers within the municipalities and private companies that are potential MagnaDrive customers.

Development of Life Cycle Cost (LCC) Model

In order to quantify the economic value of both energy and non-energy benefits of the MagnaDrive in dollar terms, the Quantec team developed an Excel spreadsheet-based tool that provides life cycle cost, simple payback, and IRR. The tool compares a VFD and a MagnaDrive ASD to a base motor and to one another. Non-energy benefits include reduced vibration, less total harmonic distortion (THD), extreme soft start, easier installation, heat dissipation, lower risk of motor and shaft damage, and lower risk of product obsolescence. With no long-term maintenance data from the field on the MagnaDrive ASD, the Quantec team used their best estimates when populating this model with data. The model inputs can be refined as field data become available.

The key model inputs included the following:

- ***Plant and motor information***. Research from Phase 1 and other VFD savings studies indicated that, on average, VFDs have energy savings of 35% for fan applications and 42% for pump applications, while MagnaDrive has energy savings of 23% and 30%, respectively.
- ***Plant downtime***. The MagnaDrive ASD is assumed to have slightly fewer downtime hours because of the benefits of soft start, decreased motor loading, and mechanical isolation from load to motor.

- ➜ ***Maintenance costs***. A number of maintenance inputs were included in the LCC model, including motor maintenance (motor windings, motor bearings and seals, electrical, thermal testing, vibration, and motor cleaning), drive train maintenance (shaft alignment, coupling, and belts), and baffles/vanes/throttles. For each of these, we examined the number of tests necessary per year, the cost per test, the number of expected repairs per year, and the average cost per repair.
- ➜ ***Capital costs***. The LCC input sheet can be used to compare capital costs for planned installation of all components in the process control system, a VFD installation, and a MagnaDrive ASD installation. Both retrofit and new motor applications were considered. Most existing motors cannot be retrofitted with state-of-the-art VFDs, so the VFD "retrofit" cases actually have the customer purchase a new motor along with the VFD. MagnaDrive ASDs, on the other hand, can be retrofitted onto most exist motor applications. Other capital costs considered include motor starters, flow control equipment, couplings or belts, RFI filters, line reactors, panel and accessories, and installation costs.

LCC Findings

Given the assumptions and data available on costs and performance, the MagnaDrive has lower life cycle costs, faster payback, and higher IRRs compared to both VFDs and the base-motor case regardless of application (pump or fan), motor size, or new versus retrofit applications.

- ➜ ***The MagnaDrive cost advantage is most pronounced for retrofit applications and larger (medium-voltage) motors***. This represents the greatest potential for the MagnaDrive ASD since VFD retrofit installations generally require the installation of a new motor. Plant managers and engineering consultants are generally unwilling to consider early replacement of a motor just to obtain speed control and related energy savings.
- ➜ ***In the case of new motors, the MagnaDrive cost advantage over VFDs is not as great***. In a new motor installation, both the VFD and MagnaDrive ASD require a new motor purchase. We believe that the results of head-to-head comparisons in new motor applications are difficult to generalize and will be site and application specific as some simple changes in the input assumptions (e.g., cost of constructing a room for the VFD) can change the economics.

- ➜ ***The savings are most resilient across a range of input sensitivities for MagnaDrive versus the base motor, less so versus VFDs***. Reasonable decreases in energy prices or increases in the cost of the ASD do not erode the savings from the ASD versus the base motor. Changes in the input assumptions for MagnaDrive versus VFDs, however, can impact the savings and the economics in either direction.
- ➜ ***More case studies are needed to investigate potential reduction in downtime/maintenance costs that could not be quantified by engineering consulting firms, VFD manufacturers, or MagnaDrive***. While we concur with engineering firms that VFDs should not receive a maintenance penalty, none are giving MagnaDrive a maintenance credit in their economic analyses. We believe that the long-term data will show these to be conservative assumptions.

I. Introduction

The Northwest Energy Efficiency Alliance (Alliance) and the MagnaDrive Corporation (MagnaDrive) have formed a public/private partnership to help commercialize the MagnaDrive adjustable speed drive (ASD). The ASD is an innovative speed-control device that transmits torque through an air gap by using powerful permanent magnets.

MagnaDrive Corporation, located in Seattle, Washington, is engaged in the development and commercialization of patented torque transfer technology with applications in industry, public works, transportation, and consumer products domestically and internationally. The Company's primary product is the MagnaDrive ASD.

The MagnaDrive Corporation and the Alliance have been working together since May 1999. Phase 1 of the project involved a number of tasks that included the testing and comparison of the ASD to variable frequency drivers (VFDs), control valves, and dampers at Oregon State University's Motor Systems Resource Facility (MSRF),[2] development of case studies of ASD installations at four industrial sites, and a confidential market assessment study.

Three key market barriers were identified in Phase 1 that MagnaDrive is diligently working to overcome:

1. Lack of in-field performance data
2. Lack of knowledge in the marketplace about the ASD as a product and technology
3. Lack of brand recognition in the marketplace of both the MagnaDrive ASD and the corporation

The overall findings from Phase 1 have led the Alliance to fund a second phase research effort designed to address these barriers. The primary goals of Phase 2 are as follows:

➜ Increase sales in the markets pursued in Phase 1 (pumps, fans and blowers; pulp and paper; water/wastewater treatment; and HVAC)

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[2] Product Testing: Magna Drive, Report No.1, Motor Systems Resource Facility, Oregon State University, March 2000 (Alliance Report #00-048).

- ➜ Expand the ASD into new target markets (larger motors 500 HP to 1000+ HP, medium- and high-voltage equipment, and irrigation)

The Alliance engaged Quantec to conduct an evaluation that will track MagnaDrive Corporation's progress toward these goals. To accomplish this, Quantec formed a project team (the Quantec team) comprised of economists, engineers, and marketing experts.

This Market Progress Evaluation Report (MPER) is the second of three progress reports that will be prepared by the Quantec team to document the progress of the Phase 2 efforts. The first MPER examined the period from August 15 – November 15, 2000, and conducted a number of tasks, including those listed below:

- ➜ ***To assess current practices, attitudes, and awareness of the MagnaDrive ASD and the speed drive market***, the Quantec team conducted interviews with four participants at demonstration sites, six customers that purchased the ASD without Alliance co-funding, four non-purchasers who were familiar with the MagnaDrive, and seven non-purchasers who were not familiar with the MagnaDrive. We also conducted interviews with the two primary trade associations for the pulp and paper and wastewater treatment industries: the Northwest Biosolids Management Association (NBMA), and the Technical Association of the Pulp and Paper Industry (TAPPI).
- ➜ ***To help estimate the Northwest market size***, we conducted "bottom-up" market-potential estimates for the wastewater treatment and pulp and paper segments, along with a database of potential Northwest purchasers.
- ➜ ***To assist the marketing staff***, we conducted a review of MagnaDrive's marketing approach that included facilitating a brainstorming/strategy session to help the company better focus its target markets, delivery channels, products, pricing, and promotions.

Alliance Phase II funding is also targeted to expansion of the MagnaDrive ASD into two specific target markets: (1) large motors (500 HP to 1000+ HP), and (2) and the irrigation market. In January 2001, MagnaDrive received a grant from the Department of Energy as part of the National Industrial Competitiveness through Energy, Environment, and Economics (NICE^3) program. The $500,000 award is for installations of four high horsepower (500 HP to 1500 HP) MagnaDrive ASDs in industrial applications and will augment Alliance Phase 2 resources. These large horsepower applications are still in the design phase so there is nothing to report on either a technical or marketing front at this time.

MagnaDrive has pursued irrigation case studies, and one is now underway. However, the regional energy crisis that occurred Winter 2000-01 forced many Northwest utilities to pay irrigators not to pump, significantly complicating the irrigation case study effort. As with the high horsepower applications, there is nothing to report at this time.

This report continues to evaluate the progress of MagnaDrive in meeting the Phase 2 objectives. It covers research and analysis conducted between November 2000 and October 2001.

The findings are divided into four sections.

- ***Chapter II: Project Characterization***: A review of the MagnaDrive project, discussing marketing and sales patterns.
- ***Chapter III. Interviews with Consulting Engineers***: In an effort to better understand how engineering consultants view MagnaDrive in relation to other speed-control devices, Quantec interviewed five consultants that attended a MagnaDrive demonstration.[3]
- ***Chapter IV. Development of Life Cycle Cost (LCC) Model***: The Quantec team developed an Excel spreadsheet-based tool that provides life cycle cost, simple payback, and internal rate of return (IRR) and is capable of comparing VFD and MagnaDrive to a base motor and to one another.
- ***Chapter V. LCC Findings***: Twelve iterations of the model were run to compare different combinations of horsepower (50 HP, 250 HP, and 500 HP), application (fans vs. pumps), and age of motor (new vs. retrofit). Following these initial runs, an extensive sensitivity analysis was performed.

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[3] We will interview additional Phase 2 purchasers and non-purchasers in 2002 for the third MPER.

II. Project Characterization

Marketing Efforts in 2001

MagnaDrive has developed and implemented an aggressive marketing plan for 2001 that targets water/wastewater, pulp and paper, HVAC, and irrigation applications for the MagnaDrive ASD. The marketing plan identifies a number of strategies to reach customers with these applications, including:

- ***Trade shows***. MagnaDrive again attended trade shows in 2001. Previous attendance at trade shows has proven extremely successful: one national trade show in 2000 led to over 500 qualified leads, some of which resulted in sales.
- ***Public relations program***. MagnaDrive will target key trade and business media for familiarization with the company and products through the use of press releases, technical papers, and journal articles.
- ***Web presence***. MagnaDrive continues to develop its Web presence by establishing a storefront on *WaterOnline*, the leading Internet water/wastewater business community, plus publishing additional articles on such sites as eco-web.com and a customer testimonial on the Whatcom County PUD Web page.
- ***Sales staff***. MagnaDrive has a full-time direct salesperson working in the pulp and paper industries, as well as working closely with several dealers that focus in this area. MagnaDrive also has a sales staff member dedicated to identifying key engineering firms and educating them about MagnaDrive through brownbag presentations.
- ***Direct mail***. MagnaDrive has established a direct mail database for ongoing distribution of appropriate marketing material, including new print and electronic collateral.
- ***Pursuing energy-efficiency government and agency programs***. MagnaDrive is positioning itself as a company with a breakthrough "green" technology with the potential to change market behavior within established industries.

This marketing plan addresses the key recommendations in the first MPER as it focuses on lead generation, trade-show participation, sales tools for direct and channel marketing partners, and third-party endorsements.

At the Alliance's suggestion, MagnaDrive has been pursuing relationships with utility, commercial, and industrial conservation program managers.

MagnaDrive Sales

As shown in Table II-1, more than half of the MagnaDrive sales have been in the water/wastewater industry (51%), far more than any other single industry. In addition, the majority of the applications have been for pumps (72%). Installations were evenly distributed between large (100 HP and over) and small (under 100 HP) motors. Finally, 79% of the MagnaDrive sales have been to customers served by a Northwest utility.

Table II-1
MagnaDrive Sales

Year	Oct-Dec 1999	2000**	Jan-May 2001	Total
Total Couplings Sold	**5**	**25**	**13**	**43**
Industry*				
Water/Wastewater	1	12	9	22 (51%)
Pulp and Paper	1	2		3 (7%)
Irrigation		3	1	4 (9%)
Industrial		1		1 (2%)
HVAC	2	1	3	6 (14%)
Energy Generation		2		2 (5%)
Other	1	5		6 (14%)
Application				
Fans	1	3	3	7 (16%)
Pumps	4	17	10	31 (72%)
Other (compressor, blower)		5		5 (12%)
Horsepower				
Under 100 HP	2	11	8	21 (50%)
100 HP or more	3	13	5	21 (50%)
Utility Location				
Northwest	5	19	9	33 (79%)
Other location	0	5	4	7 (21%)

* Some applications span more than one industry
** One sale did not have HP or utility information

While MagnaDrive is on track for a modest increase in ASD sales in 2001, the increase is far less than hoped for by the Alliance or the MagnaDrive Corporation. However, 2001 sales have been hampered by two forces outside of MagnaDrive's control:

➜ ***Widely fluctuating electricity prices***. Northwest wholesale electric prices have ranged from around of $400/MWh in the first quarter to

$20/MWh in the fall of 2001. This volatility and uncertainty has impacted the entire speed-control market. One Northwest VFD manufacturer representative said, “our sales are down significantly. My industrial customers don’t know whether to install cogeneration facilities, energy-efficient technologies like VFDs, or do something else.”

➜ ***A manufacturing slowdown***. The U.S. is in recession, and the manufacturing sector has been hit harder than most sectors of the economy. Capital budgets have been slashed or frozen. Notice in Table II-1 that no sales were made through May 2001 to the pulp and paper industry or other industrial customers. The total number of pulp and paper facilities in the Northwest has fallen to about 30 facilities from the 40-plant figure reported in the first MPER. Two large mills shut down (Georgia Pacific in Bellingham,Washington, and Abitibi in Steilacoom, Washington), and several plants have curtailed production or have permanently shut down portions of their facilities. In addition to the general manufacturing slowdown, the industry has been hard hit by the double whammy of high electricity prices and low pulp prices. Inland Empire Paper in Millwood, Washington, was the only plant that increased its paper capacity during this period.

III. Engineering Firm Interviews

To assess current practices, attitudes, and awareness of the MagnaDrive and the speed drive market, the Quantec team conducted interviews with a number of purchasers and non-purchasers of MagnaDrive for the first MPER.

Some industries rely heavily on the advice of engineering firms for capital improvement or expansion decisions. This reliance is particularly acute in the municipal water and wastewater industry, a key target market for the MagnaDrive ASD. In an effort to better understand how engineering firms view the MagnaDrive ASD in relation to other speed-control devices, Quantec interviewed five engineering consultants for the current MPER.

Interview Design

The consultants were selected from a list of 42 contacts provided by MagnaDrive – all of whom had attended a MagnaDrive demonstration and were familiar with the MagnaDrive technology. Some of the consultants worked at large, national consulting firms (e.g., Black and Veatch, CH2M Hill, etc.) while others worked at smaller, regional firms (e.g., Gray and Osborn). Quantec attempted to speak with consultants in both larger and smaller firms. In addition, we interviewed engineers working in the Northwest, where MagnaDrive is located and where the marketing efforts have been focused. The interviews focused on their speed-control recommendations.

The interviews were conducted between March 23 and April 12, 2001. The interview instrument, included in Appendix A, took approximately 30 minutes to administer. The questions were all open-ended and allowed the respondent to provide detailed feedback. The sample size was limited to five based on budgetary limitations, but the detailed responses provide valuable qualitative insights into the consulting engineers' perspectives about MagnaDrive's role in the speed-control market.

The interviews were designed to elicit the following general information:

➜ ***Perceptions regarding motors and speed-control devices***. Do engineers recommend speed-control devices? How have technological changes in speed-control devices influenced the perception towards speed control? How do O&M costs compare for standard motors versus motors with speed-control devices? What is the future demand for speed-control devices?

- ➜ ***Perceptions regarding MagnaDrive***. How is MagnaDrive viewed in the marketplace? What are its perceived advantages and disadvantages? How does it compare against other forms of speed-control devices? What are the best applications for MagnaDrive?
- ➜ ***Recommendation criteria***. What kind of costing analyses are performed – simple payback or life cycle costs? What costs are considered in the financial analysis – only energy costs? Non-energy costs/benefits (such as operations and maintenance)? Is cost the primary motivator? What other motivators were there?

Findings

The engineers generally do not believe that VFDs have higher O&M costs than regular motors. All five engineers felt comfortable recommending VFDs for the applications where they are needed; they did not have any reservations about costly O&M expenses for VFDs. Some of the engineers even seemed surprised at this suggestion and said they wouldn't recommend VFDs if they thought they had unreasonable O&M costs. Respondents could not comment on the O&M costs for MagnaDrive versus regular motors as the respondents believed MagnaDrive was still too new a technology to know the O&M costs. Two respondents even felt the O&M savings from MagnaDrive had been distorted, or "shaded," in the literature in order to make them look larger.

MagnaDrive is not recommended because of the uncertainty associated with a new product. All of the respondents pointed out the uncertainty of recommending a new product to their clients. As one respondent said, "no one wants to be the first one on the block to adopt a new technology with so many unknowns." Many of the consulting firms, therefore, stay within their "comfort zones" and recommend products that they are familiar with. A few of the engineers even admitted that their companies have standard (generic) motor specifications that they recommend for their clients, using established technologies they are experienced and comfortable with. The engineers all agreed that, ultimately, it was their clients that were making the final decision, so their clients had to be comfortable with MagnaDrive.

Some engineers are not taking the time to fully investigate the pros and cons of MagnaDrive. In addition to having standard sets of recommendations, respondents are not comparing their current favorite products with MagnaDrive. While they were all interested in the product, most of the engineers weren't really sure how it compared in terms of energy consumption, non-energy benefits (such as reductions in harmonic distortion), or, in certain situations, space requirements that are small relative to VFDs.

(One decision-maker even believed that the MagnaDrive ASD could have special space requirements that are more expensive than those associated with VFDs).

Some clients prefer specifications that can be competitively bid. One respondent indicated that they like to recommend system “specs” that municipalities can put out to bid. MagnaDrive, as the only producer of the MagnaDrive ASD, might be viewed as a sole-source recommendation. And, as discussed above, engineers are not taking the time to compare MagnaDrive with VFDs.

Early retirement of motors is not normally considered. All five of the engineers reported that they have never recommended early retirement of motors. One engineer said that he would consider it, but in reality he had never recommended it.

Respondents are easy to reach and seem to be interested in information about MagnaDrive. It was generally easy to reach the respondents and spend approximately 30 minutes with them on the telephone. Most of the engineers also seemed generally interested in the MagnaDrive technology and learning more about it.

Recommendations

Until supporting data can be collected from its installations, MagnaDrive should not overemphasize the O&M savings from the MagnaDrive ASD. While MagnaDrive may lead to some O&M savings, the five engineers we spoke with did not view these savings as substantial or guaranteed. MagnaDrive should therefore be careful to mention, but not to overemphasize, the potential O&M savings from the MagnaDrive ASD.

MagnaDrive needs to continually remind the decision-makers about MagnaDrive technology. The respondents were unaware of the benefits of MagnaDrive yet quite interested in learning more. Accordingly, MagnaDrive should maximize the number of mailings, phone calls, and visits to the appropriate decision-makers. Ideally, this would be a combination of a low-cost marketing and targeting that creates more publicity, particularly among the major national and regional engineering firms. One engineer specifically asked for more information during the interview. MagnaDrive needs to continue to contact these people to remind them of MagnaDrive’s benefits. Another engineer suggested occasional brown bag lunches or even having MagnaDrive supply lunch to attract a bigger crowd.

Need to get clients asking for MagnaDrive in the specifications, supply even more case studies, and allay these early adopter fears. All of the engineers agreed that their clients are the ultimate decision-makers and that they are wary about recommending a new technology. Thus, MagnaDrive must continue to educate not only the consultants but also the decision-makers within the municipalities and private companies that are potential MagnaDrive customers. When the purchasers begin asking about MagnaDrive, the consultants will receive the necessary "pull" to fully investigate and potentially recommend the product.

IV. Development of Life Cycle Cost Model

Background

Prior research has shown that the MagnaDrive saves approximately two-thirds of the energy saved by VFDs.[4] Since the ASD and competitive VFDs have similar pricing structures, the MagnaDrive is, on the surface, competitive only in sub-markets where speed control is not currently being used.

Non-energy benefits, however, may make the ASD economically viable relative to VFDs and other speed-control devices in certain cases. Non-energy benefits already identified by the Alliance and the Oregon State University MSRF include:

- ➜ Reduced vibration due to the motor not having a physical connection with the load
- ➜ Less total harmonic distortion (THD) from the MagnaDrive ASD relative to VFDs and THD levels that are very similar to directly connected motors.
- ➜ Extreme soft start as the drive allows the motor to start completely unloaded
- ➜ Easier installation due to greater leeway in the shaft alignment and the distance between a typical VFD located at the motor control center and the motor itself. There is a limit to the distance between the VFD and motor. The MagnaDrive is installed on the motor and, thus, can be installed in remote locations.
- ➜ Better heat dissipation than VFDs. VFD technologies have improved but still need to dissipate heat, which can limit where they can be installed.
- ➜ Lower risk of motor and shaft damage in certain retrofit applications relative to VFDs

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[4] As noted in the Phase 1 study "Product Testing: Magna Drive, Report No.1," prepared by the Motor Systems Resource Facility (MSRF) at Oregon State University, "the MagnaDrive Coupling achieves an average of 62% of the VFD energy savings for fans, and 65% of the VFD savings for pumps." (p. 9)

➜ Lower risk of product obsolescence relative to a rapidly changing VFD component market. MagnaDrive guarantees parts availability for 20 years (compared to two years or less for most VFDs), and there are fewer parts relative to VFDs.

The goal of this task is to understand how these non-energy benefits may expand and change the speed-control market. Impacts of these benefits may be felt in current speed-control applications such as increases in mean time between failures, longer motor and ASD lives, lower maintenance costs, and downsizing of motors. They may also help expand the use of speed controls in niche markets where VFDs are not currently used, such as marginal variable loads, non-traditional variable loads (e.g., where loads shift week-to-week or year-to-year), and areas where power quality is sub-standard.

In order to quantify the economic value of both energy and non-energy benefits in dollar terms, the Quantec team developed an Excel spreadsheet-based tool that provides LCC, simple payback, and IRR. The tool is capable of comparing both VFD and MagnaDrive to a base motor and to one another.

The LCC calculations were performed over a 20-year planning horizon. The current form of the model does not differentiate between the life of the motor versus the life of a speed-control device. The life of the MagnaDrive is estimated to be 15 years, and the life of the VFD is estimated to be ten years for small and medium motors, and 15 years for large motors of a new motor at that time get reflected in the LCC.[5]

Inputs

The key model inputs included four general sections: plant and motor information, maintenance costs and reduction in downtime, capital costs, and energy data and rates. Appendix B discusses, in detail, the values and data sources that were used for each of these inputs. We discuss general assumptions that were made for the LCC model in the text and Tables IV-1 through IV-3 below.

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[5] As mentioned previously, in the retrofit case the VFD gets a new motor and the MagnaDrive ASD keeps the old motor. However, the old motor may have a shorter service life and require more maintenance than a new one, especially if we are putting off buying a new motor by several years by purchasing the MagnaDrive ASD. Yet, several purchases of the MagnaDrive ASD noted during interviews conducted for the first MPER that they have a spare motor that they will use with the MagnaDrive ASD if the primary motor needs to be retired. We plan to enhance the LCC model and re-interview MagnaDrive ASD purchasers to address these complex replacement issues in the third MPER.

Plant and Motor Information

As shown in Table IV-1 below, a number of assumptions were made regarding the plant operation and motor use. Research from Phase 1 and other VFD savings studies indicated that, on average, VFDs have energy savings of 35% for fan applications and 42% for pump applications, while MagnaDrive has energy savings of 23% and 30%, respectively. In addition, we assumed that motors controlled by the MagnaDrive ASD will have slightly fewer downtime hours (10% less) because of the benefits of soft start, decreased motor loading, and mechanical isolation from load to motor.

Maintenance Costs and Reduction in Downtime

A number of maintenance inputs were included in the LCC model, including motor maintenance (motor windings, motor bearings and seals, electrical, thermal testing, vibration, and motor cleaning), drive train maintenance (shaft alignment, coupling, and belts), and baffles/vanes/throttles. For each of these, we examined the number of tests necessary per year, the cost per test, the number of expected repairs per year, and the average cost per repair.

As shown in Tables IV-2 and IV-3 below, there were a number of assumed advantages of MagnaDrive over a base motor, including fewer motor rewinds, longer life for motor bearings and seals, and fewer shaft alignments. In addition, MagnaDrive motors no longer have the need for belts, baffles, vanes, and throttles.

Certain VFD drawbacks – changing harmonics, over-voltage, and poor cooling at low speeds – warrant increased electrical testing and repairs, increased thermal testing, and increased vibration testing.

Capital Costs

The input sheet can be used to compare capital costs for planned installation of all components in the process control system or installation of a VFD or MagnaDrive onto an existing system. Both retrofit and new motor applications were considered. Most existing motors cannot be retrofitted with state-of-the-art VFDs, so the VFD “retrofit” cases actually have the customer purchase a new motor along with the VFD. MagnaDrive ASDs, on the other hand, can be retrofitted onto most exist motor applications. Other capital costs considered include motor starters, flow control equipment, couplings or belts, RFI filters, line reactors, panel and accessories, and installation costs.

Energy Data and Rates

Quantec assumed an average industrial energy rate of 5 cents/kWh. Discount rates were assumed to be 9%, with rates for inflation (general, machinery, and electricity prices) set to 3.5%.

Table IV-1
General LCC Inputs

Input	Discussion for Base Motor, VFD, and MagnaDrive ASD
Horsepower	Quantec ran models for 50 HP, 250 HP, and 500 HP scenarios. Motors were assumed to run at 1800RPM.
Annual Operating Hours	This value is computed as Hours per shift*Number of Shifts*Number of Days worked per week*52 weeks*Duty cycle
Motor Loading	This value equals the load driven by the motor: the movement of liquid for pumps or the movement of air for fans. The load distribution is given in % of max fluid flow required for each hour in a sixteen hour (two-shift) time period. It is assumed that the flow is being controlled by a throttle valve in the pump-input sheets and baffles in the fan-input sheets.
Efficiency	The difference between the VFD and MagnaDrive controlled motors and throttle-controlled motor was divided by the max power rating of the motor to determine a percentage of energy savings at each percent fluid flows (pff). The resulting value was multiplied by the time duration of the flow level (1 hour for all flows in this load distribution). The resulting column of data was summed and then divided by the total hours the motor was on to arrive at an average energy savings.
Downtime	Downtime is dependent on motor application, motor environment, and maintenance procedures. Larger motors usually take more time to fix and due to cost, are less likely to have backup motors. Smaller motors are more likely to be neglected. These input sheets scale unexpected downtime to motor size. It is assumed that there is no difference in the pump and fan applications. Although VFDs can be a source of harmonics most problems associated with VFDs have known mitigations, so it is assumed that the expected downtime of a motor with a VFD will be the same as a stand-alone motor. It is assumed that motors controlled by the MagnaDrive ASD will have slightly less downtime hours because of the benefits of soft start, decreased motor loading, and mechanical isolation from load to motor.
Service Life of Motor Speed-control Device	The life expectancy of a motor depends on the motor's environment, load distribution, maintenance practices, quality of input power and other variables. It is also assumed that if the maintenance procedures outlined in the input sheet, both the motor and speed-control devices will have the same service life.

Table IV-2
Motor Maintenance Inputs

Input	Discussion for Base Motor, VFD, and MagnaDrive ASD
Motor Windings	
Test Motor Windings	This test falls under the category of insulation resistance testing. There are a number of special insulation resistance tests that can reveal degradation in insulation. Establishing a testing schedule is an iterative process. When a motor is installed it is often necessary to prescribe somewhat frequent intervals at first, then experiment with lengthening the intervals. It is assumed that costs scale to motor size and are the same for the three control schemes investigated. –
Rewind	Windings fail when insulation degrades, usually due to some combination of over heating, aging, and over-voltage transients. We assumed that a rewind will be required less frequently in the MagnaDrive case.
Motor Bearings and Seals (MBS)	
Preventive Maintenance	MBS preventive maintenance includes checking bearing temperature, oiling bearings, and a thorough visual inspection.
Repairs	The life of the bearings is dependent on many variables including vibration, alignment, motor cleanliness, and greasing frequency. We assumed that bearing life is extended in the MagnaDrive case. Note that this is the period between bearing repairs, not the service life of the motor.
Electrical	
Testing	Testing includes electrical monitoring of voltage and current, power factor, phase balance line harmonics, current and voltage balance, as well as visual inspection of fuses and connections etc. It is assumed that this interval is the same for the three motor sizes and does not vary in the two applications and between the MagnaDrive and base motor, but that VFDs have harmonics that may be damaging to electrical components and are assumed to require more testing.
Electrical Repair	Electrical repair cost is dependent on what in the electrical system has malfunctioned and has a wide range. Costs scale to motor size and are the same in the two applications considered and in the MagnaDrive and base-motor scenarios. It is also assumed that repairs involving VFD will be more expensive and time consuming because of the added electrical complexity.
Thermal Testing	
Motor Temperature tests	It is assumed that this interval is the same for the three motor sizes and does not vary in the two applications considered (fans and pumps). The interval does not vary between the MagnaDrive and the base motor, but certain VFD drawbacks – changing harmonics, over-voltage, and poor cooling at low speeds – warrant increased thermal testing for VFDs. The cost per test is assumed not to vary with motor size, application, or motor control strategy.
Vibration	
Vibration Tests	A change in vibration often signals a bearing problem. It can also signal other problems like load imbalance, bent shaft, rotor damage, increase or change in line harmonics, and coupling misalignment. It is assumed that this interval is the same for the three motor sizes and does not vary in the two applications considered. The interval also does not vary between the MagnaDrive and the base motor, but VFDs are assumed to be checked more frequently because the increase or change in harmonics and load imbalance can cause vibration.
Motor Cleaning	
Cleaning	Cleaning the motor casing and the ventilation filters is important because the operating temperature increases as dust and dirt accumulate. Cooler motors operate more efficiently and have longer lifetimes. It is assumed that the cleaning period does not vary with motor size or the two applications considered. It is assumed that cleaning costs scale with motor size

Table IV-3
Other Maintenance Inputs

Input	Discussion for Base Motor, VFD, and MagnaDrive ASD
Shaft Alignment (Drive Train)	
Alignment	It is assumed that the number of alignments is not a function of motor size or application, and that the interval between alignments will stay the same between base motors and VFDs. Alignments should occur less frequently with the MagnaDrive ASD. It is assumed that alignment costs scale with motor size stay the same in the pump and fan applications. It is also assumed that MagnaDrive alignments are less expensive because the ASD allows for greater misalignment. MagnaDrive motors will not require any alignment except when the motor or pump is removed for repairs.
Coupling (Drive Train)	
Testing	Most maintenance associated with couplings has to do with proper alignment, and thus tests are shown under the alignment section for base motors and VFDs. The MagnaDrive ASD is a new product and consequently, unpredictable problems may arise. Yet, the tests would happen in the first year, therefore over the life of the model, it is assumed that the tests are zero per year.
Repair	It is assumed that the MagnaDrive ASD will last longer than other industrial couplings. However, MagnaDrive is a more complicated and expensive coupling, so it is assumed that the cost of repairing the MagnaDrive ASD will be greater than the cost of repairing an ordinary industrial coupling. Repair costs for all couplings scale to motor size.
Belts (Drive Train)	
Testing	The user of this input sheet may not have a belt driven system. In this case the user should enter zero in all inputs associated with belts. Assumed that cost of tests is not a function of application or motor control scenario and that it scales with motor size.
Repair	Due to the soft start of most VFDs it is assumed that the typical life of the belt will be extended. Assumed that repair cost is not a function of motor control scenario or application and that cost scales with motor size.
Baffles/Vanes/Throttles (Flow Control)	
Testing	When a VFD or a MagnaDrive is introduced into applications there is no longer a need for these types of mechanical controls. Consequently, there are no inputs for VFDs and MagnaDrive associated with this category. For base motors it was assumed that the cost of tests don't vary with either motor size or application.
Repair	Assumed that cost of repair will scale to motor size.

Finally, we assumed in all cases that no additional buildings or additions need to be constructed and that there is sufficient room to house a VFD in the existing motor-control center. If a customer is purchasing his first and only VFD, construction costs would need to be added to the capital costs. The additional of construction costs to this LCC will naturally improve the payback performance of the MagnaDrive ASD relative to a VFD.

If, however, the customer already has a number of VFDs or they are planning to buy several VFDs, then it is unnecessary to add square footage costs to the model. Indeed, the foot print of VFDs is shrinking, and every time an older VFD is removed there is probably room for as many as five new ones.

V. Life Cycle Cost Findings

Initially 12 iterations of the model were run to compare different combinations of horsepower (50 HP, 250 HP, and 500 HP), application (fans vs. pumps) and age of motor (new vs. retrofit). Following these initial runs, an extensive sensitivity analysis was performed.

Model Results

Retrofit Models

The results of the retrofit models (Table V-1) indicate that both MagnaDrive and VFDs have lower life cycle costs compared to the base. These results are consistent for all the scenarios examined. The savings for both MagnaDrive and VFDs are slightly greater in the case of pumps than for fans due to the differences in energy savings.

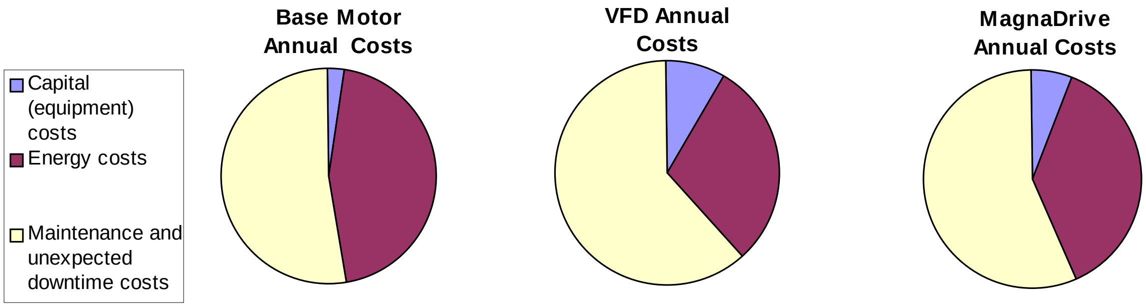
Table V-1
Retrofit Application Results

Application and Motor Size	Initial Investment			Annual After-Tax Life Cycle Costs			Payback (years)		IRR	
	Base Motor	MagnaDrive ASD	VFD*	Base Motor	MagnaDrive ASD	VFD	Magna Drive	VFD	Magna Drive	VFD
Fans										
50 HP	$0	$15,200	$18,743	$25,561	$23,689	$25,887	5	9	22%	7%
250 HP	$0	$30,000	$68,180	$79,072	$70,012	$74,631	3	6	38%	17%
500 HP (MV)	$0	$57,000	$157,240	$159,282	$141,450	$150,901	3	7	39%	15%
Pumps										
50 HP	$0	$15,200	$18,823	$25,530	$23,120	$25,338	5	8	25%	10%
250 HP	$0	$30,000	$68,400	$79,019	$66,992	$72,031	3	5	46%	20%
500 HP (MV)	$0	$57,000	$125,600	$159,232	$134,584	$145,786	3	6	47%	18%

* VFD investment includes new motor since most existing motors cannot be retrofitted with a VFD.

Figure V-1 below shows a representative pie chart that indicates what the share of the costs of in the total life cycle are (e.g. investment: capital costs, energy costs, and maintenance/unexpected downtime costs).

Figure V-1
250 HP Retrofit Pump Annual Costs



In addition, MagnaDrive has lower life cycle costs, faster payback, and higher IRRs compared to both VFDs and the base-motor case regardless of application (pump or fan) or motor size. The cost effectiveness is most pronounced for larger motors. For example, when installing MagnaDrive on a retrofit pump, the IRR increases from 25% for 50 HP motors to 47% for 500 HP motors, while the IRR for VFDs only increases from 10% to 18% for the same motors.

This analysis does not account for potential utility rebates, which could further lower the payback to less than two years in some scenarios. Note also that this analysis assumes that retrofit installations of VFDs require installation of a new motor, whereas the MagnaDrive ASD can be installed as a true retrofit.

New Motors

The life cycle cost analysis for the new motor scenarios had results similar to the retrofit models:

- ➜ MagnaDrive has the lowest life cycle costs
- ➜ Paybacks are lower and IRRs higher for MagnaDrive
- ➜ Paybacks and IRRs improve with larger motors and drives
- ➜ Pump economics are slightly better than fans

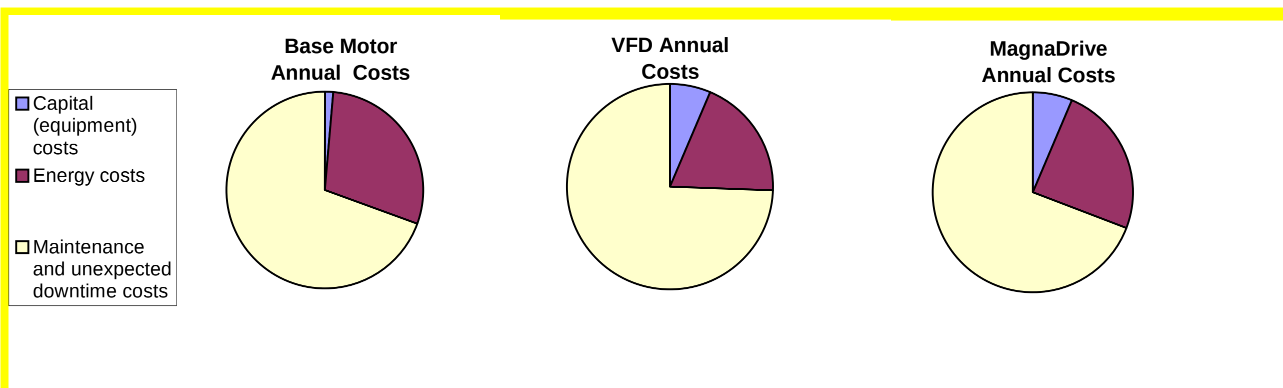
The one major difference from the retrofit models, however, is that, since both the base motor and MagnaDrive now have higher capital costs, the VFD economics improve (Table V-2). Although the MagnaDrive life cycle costs remain lower than VFDs' (with faster paybacks and higher IRRs), these benefits are less pronounced than in the retrofit models, especially at the 50 HP and 250 HP levels.

Table V-2
New Motor Results

Application and Motor Size	Initial Investment			Annual After-Tax Life Cycle Costs			Payback (years)		IRR	
	Base Motor	MagnaDrive ASD	VFD	Base Motor	MagnaDrive ASD	VFD	Magna Drive	VFD	Magna Drive	VFD
Fans										
50 HP	$5,020	$19,100	$18,743	$26,060	$24,616	$25,887	6	7	20%	11%
250 HP	$24,930	$52,750	$68,180	$81,553	$72,592	$74,631	3	4	41%	27%
500 HP (MV)	$50,240	$104,000	$157,240	$164,281	$144,970	$150,901	3	5	42%	22%
Pumps										
50 HP	$5,100	$19,100	$18,823	$26,038	$24,087	$25,338	5	6	23%	15%
250 HP	$25,150	$52,750	$68,400	$81,522	$70,023	$72,031	3	4	46%	32%
500 HP (MV)	$50,600	$104,000	$157,600	$164,266	$140,245	$145,786	3	5	49%	26%

Figure V-2 below shows a representative pie chart that indicates what the share of the costs of in the total life cycle are (e.g. investment: Capital costs, energy costs, and maintenance/ unexpected downtime costs).

Figure V-2
50 HP New Fan Annual Costs



Sensitivity Analysis

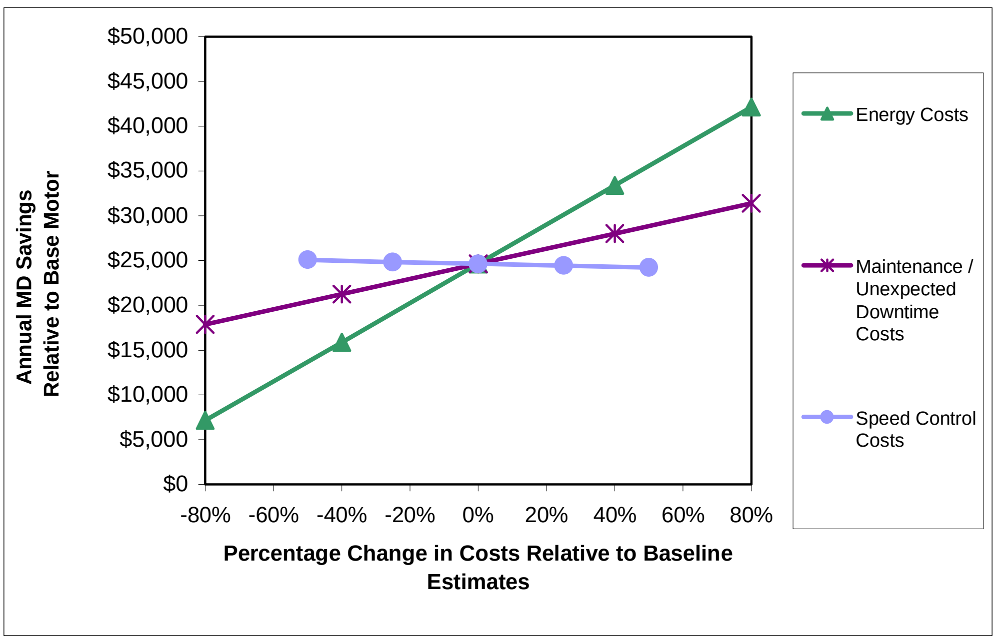
The Quantec team performed a sensitivity analysis to examine how sensitive the base case results are to changes in maintenance/downtime costs, energy prices, and first (capital) costs. To accomplish this, we varied one parameter at a time relative to the baseline assumptions. Specifically, the sensitivity analysis included the following parameters:

- ➜ Energy prices (± 80%)
- ➜ Maintenance/downtime costs (± 80%)

➜ Capital costs[6] (± 50%)

To see how the sensitivity analysis works, consider Figure V-3. It compares MagnaDrive savings relative to a base motor for a 500 HP retrofit pump application. The horizontal axis measures the percentage change (+ or -) in a model input parameter relative to the baseline. The vertical axis measures the change in annual savings when comparing MagnaDrive with base motors. As shown in this figure, as energy costs and maintenance/downtime costs increase, the MagnaDrive savings increase, but the ASD costs have little affect.

Figure V-3
Sensitivity Analysis for MagnaDrive vs. Base Motor, 500 HP Retrofit Pump



➜ Increases in energy costs will significantly increase the economic performance of the MagnaDrive ASD.

➜ Changes to maintenance costs, unexpected downtime need to be quite large to impact the economic performance of the MagnaDrive ASD.

➜ Changes in the price of the MagnaDrive ASD costs have little impact on life cycle economic performance.

➜

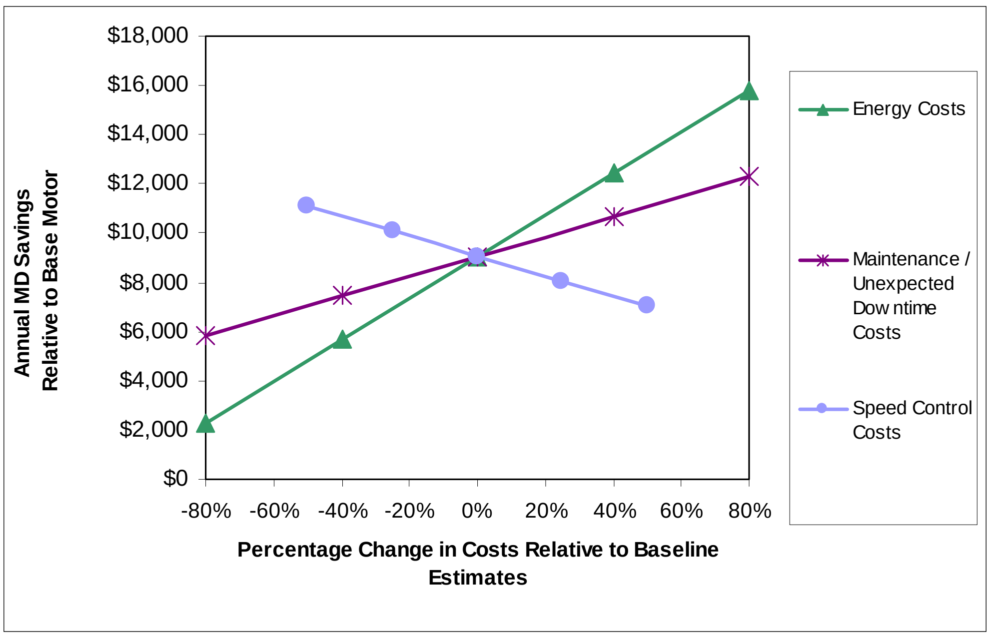
[6] Capital costs for MagnaDrive and VFD are adjusted up or down, but not relative to one

In the following discussion, we will show three charts as examples. We will show a 500 HP pump, 250 HP fan and 50 HP pump.

MagnaDrive versus Base Motor for Retrofits

The findings, as illustrated by the examples presented in Figure V-3 above and Figures V-4 and V-5 below, indicate that annualized MagnaDrive LCC savings relative to base motor are present given reasonable input sensitivities. Little or no downtime and/or zero lost production costs do not affect the conclusion, and energy savings alone justify the MagnaDrive retrofit relative to a base motor. In addition, drive costs could rise considerably without affecting the conclusion, and electricity prices would need to fall below historical lows (2 cents/kWh) for the savings to dissipate.

Figure V-4
Sensitivity Analysis for MagnaDrive vs. Base Motor, 250 HP Retrofit Fan

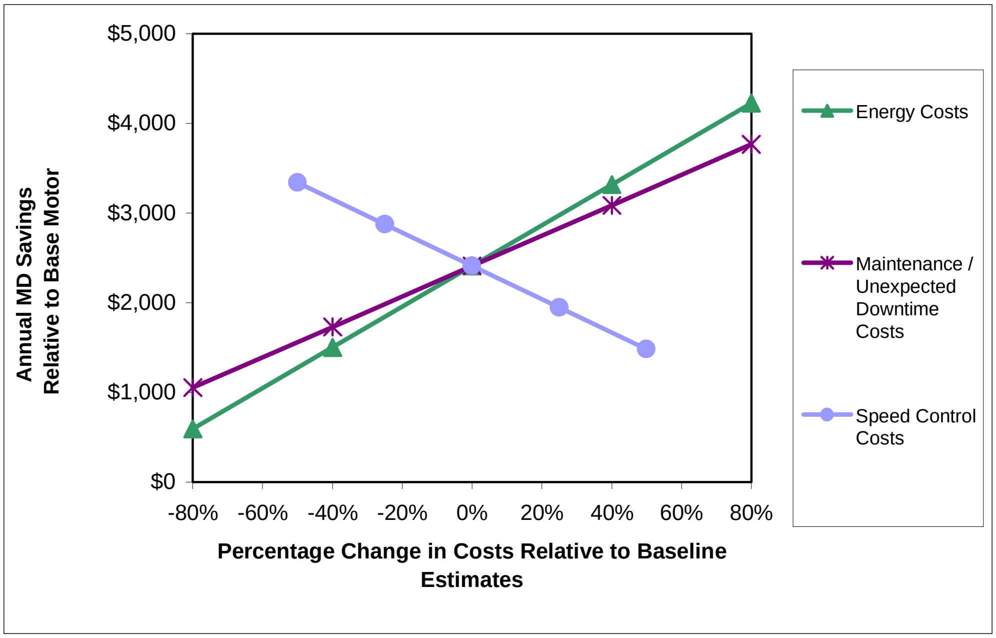


- ➜ Increases in energy costs will significantly increase the economic performance of the MagnaDrive ASD.
- ➜ Increases in maintenance costs and unexpected downtime costs also positively impact the economic performance of the MagnaDrive ASD.
- ➜ Increases in the price of the MagnaDrive ASD costs reduce the economic performance of the ASD, but it remains an attractive investment over a broad range of price increases.

➜

another, with the assumption that any price advantage is transitory.

Figure V-5
Sensitivity Analysis for MagnaDrive vs. Base Motor, 50 HP Retrofit Pump

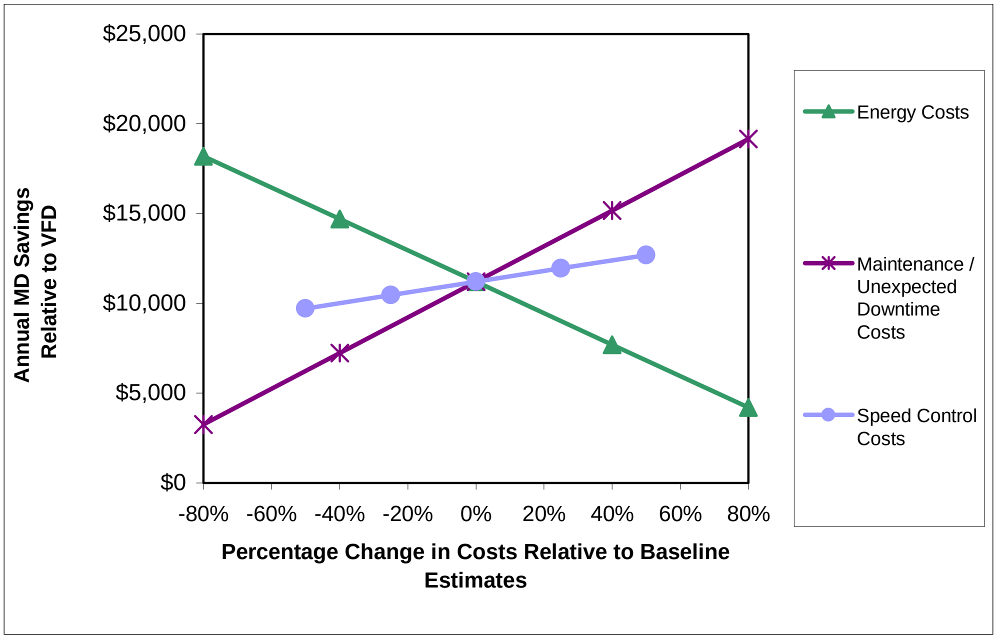


➜	Increases in energy costs will significantly increase the economic performance of the MagnaDrive ASD.
➜	Increases in maintenance/downtime costs will significantly increase the economic performance of the MagnaDrive ASD.
➜	Increases speed-control costs will negatively impact the economic performance of the MagnaDrive ASD, but price increases need to be quite large to reverse the life cycle advantage of the ASD.

MagnaDrive versus VFD for Retrofits

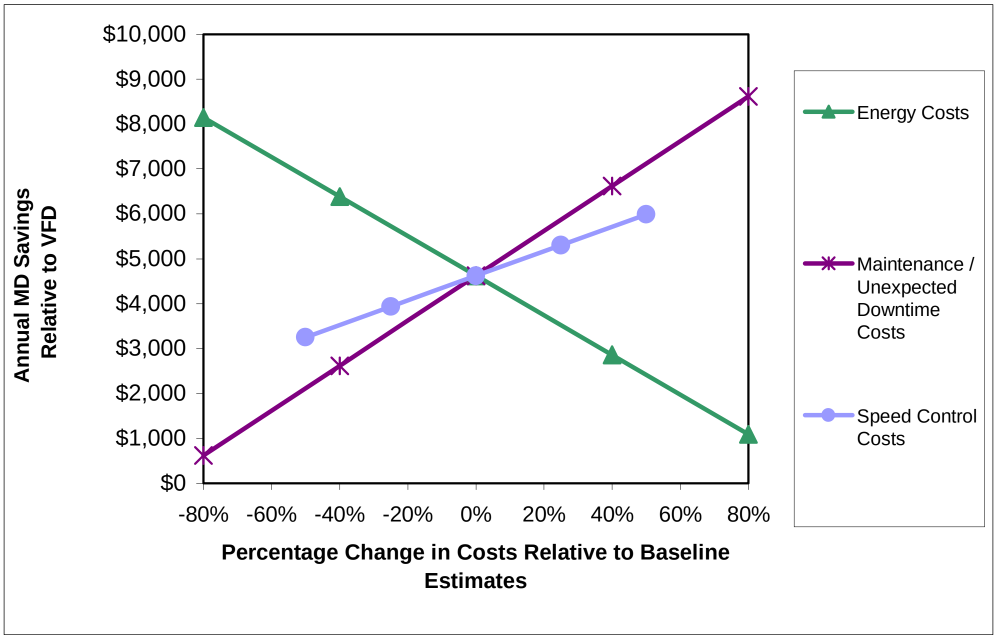
Annualized MagnaDrive LCC savings relative to VFD are not as clear cut, but do exist across broad ranges of input sensitivities (Figures V-6 through V-8). However, the results also show that potential customers and their engineering consultants should perform detailed, customer-specific life cycle economic analyses prior to purchasing a speed-control device.

Figure V-6
Sensitivity Analysis for MagnaDrive vs. VFD, 500 HP Retrofit Pump



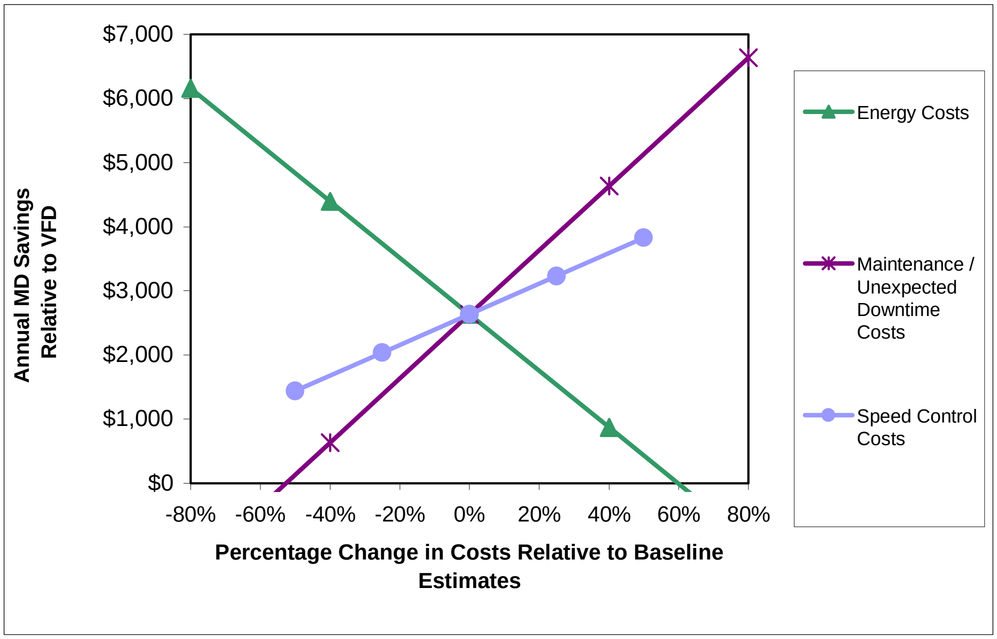
➜	Increases in energy costs will decrease the economic performance of the MagnaDrive ASD relative to the VFD.
➜	Increases in maintenance/downtime costs will significantly increase the economic performance of the MagnaDrive ASD relative to the VFD.
➜	Changes in speed-control costs need to be very large to impact the economic performance of the MagnaDrive ASD relative to the VFD.

Figure V-7
Sensitivity Analysis for MagnaDrive vs. VFD,
250 HP Retrofit Fan



➜	Increases in energy costs will decrease the economic performance of the MagnaDrive ASD relative to the VFD.
➜	Increases in maintenance/downtime costs will increase the economic performance of the MagnaDrive ASD relative to the VFD.
➜	Increases in speed-control costs will positively impact the economic performance of the MagnaDrive ASD relative to the VFD.

Figure V-8
Sensitivity Analysis for MagnaDrive vs. VFD, 50 HP Retrofit Pump

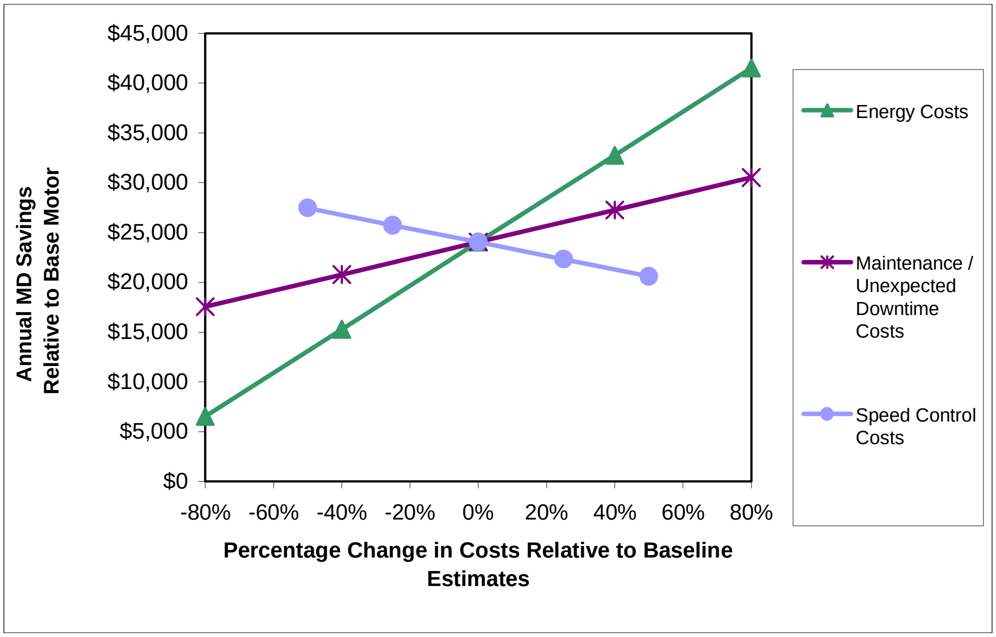


- ➜ Increases in energy costs will decrease the economic performance of the MagnaDrive ASD relative to the VFD.
- ➜ Increases in maintenance/downtime costs will increase the economic performance of the MagnaDrive ASD relative to the VFD.
- ➜ Increases in speed-control costs will positively impact the economic performance of the MagnaDrive ASD relative to the VFD.

MagnaDrive versus Base Motors for New Motors

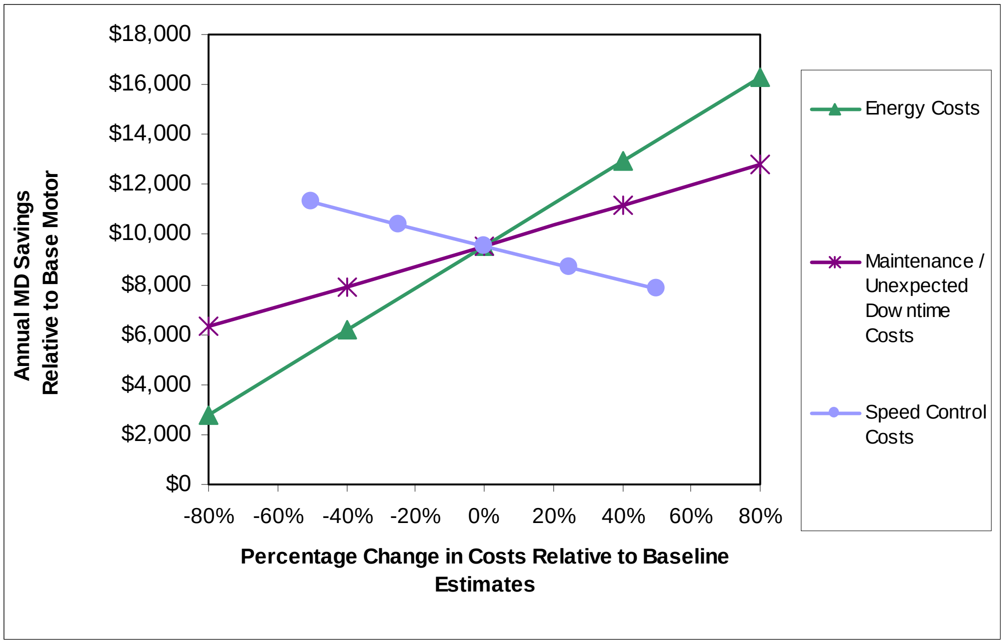
As in the retrofit example, annualized MagnaDrive LCC savings relative to base motor exist across a broad range of input sensitivities (Figures V-9 through V-11).

Figure V-9
Sensitivity Analysis for MagnaDrive vs. Base Motor, 500 HP New Pump



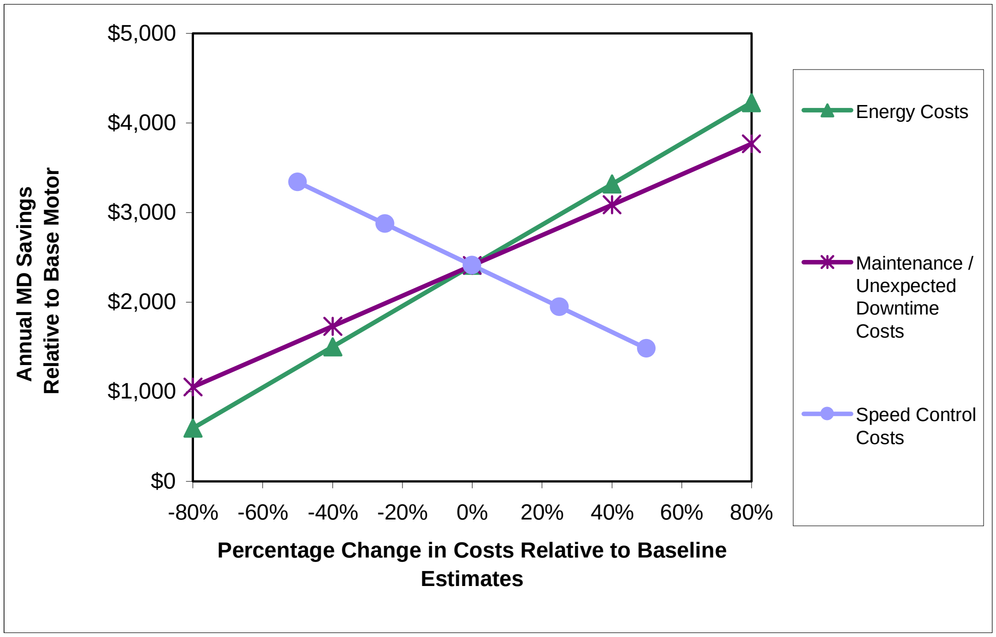
➜	Increases in energy costs will increase the economic performance of the MagnaDrive ASD.
➜	Increases in maintenance/downtime costs will increase the economic performance of the MagnaDrive ASD.
➜	Changes to speed-control costs need to be quite large to impact the economic performance.

Figure V-10
Sensitivity Analysis for MagnaDrive vs. Base Motor, 250 HP New Fan



➜	Increases in energy costs will increase the economic performance of the MagnaDrive ASD.
➜	Increases in maintenance/downtime costs will increase the economic performance of the MagnaDrive ASD.
➜	Changes to speed-control costs need to be quite large to impact the economic performance.

Figure V-11
Sensitivity Analysis for MagnaDrive vs. Base Motor,
50 HP New Pump

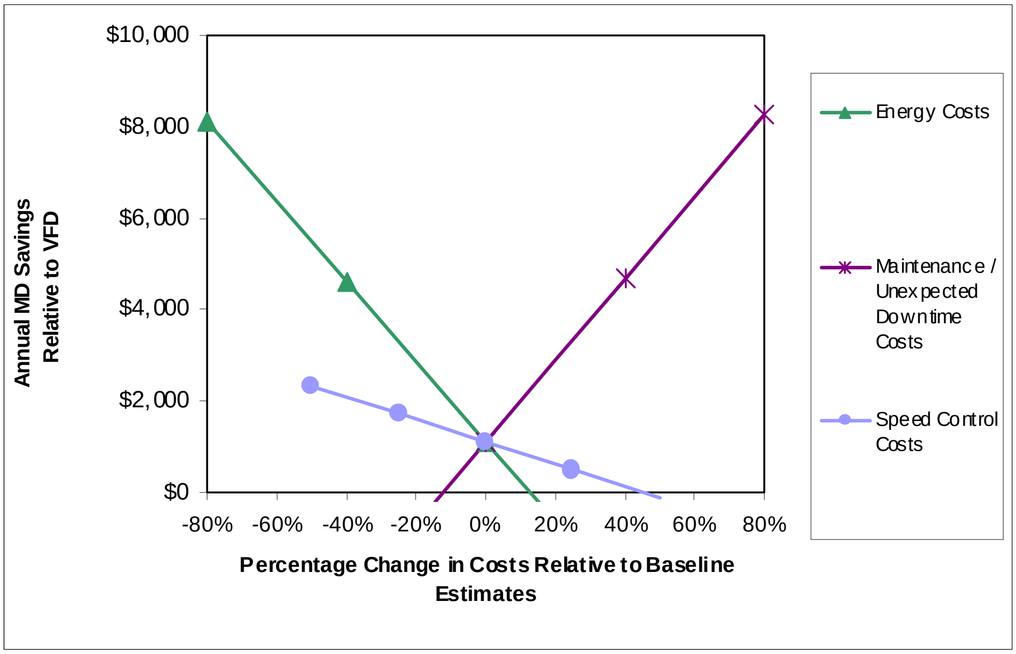


➜	Increases in energy costs will increase the economic performance of the MagnaDrive ASD.
➜	Increases in maintenance/downtime costs will increase the economic performance of the MagnaDrive ASD.
➜	Increases in speed-control costs will negatively impact the economic performance of the MagnaDrive ASD.

MagnaDrive versus VFD for New Motors

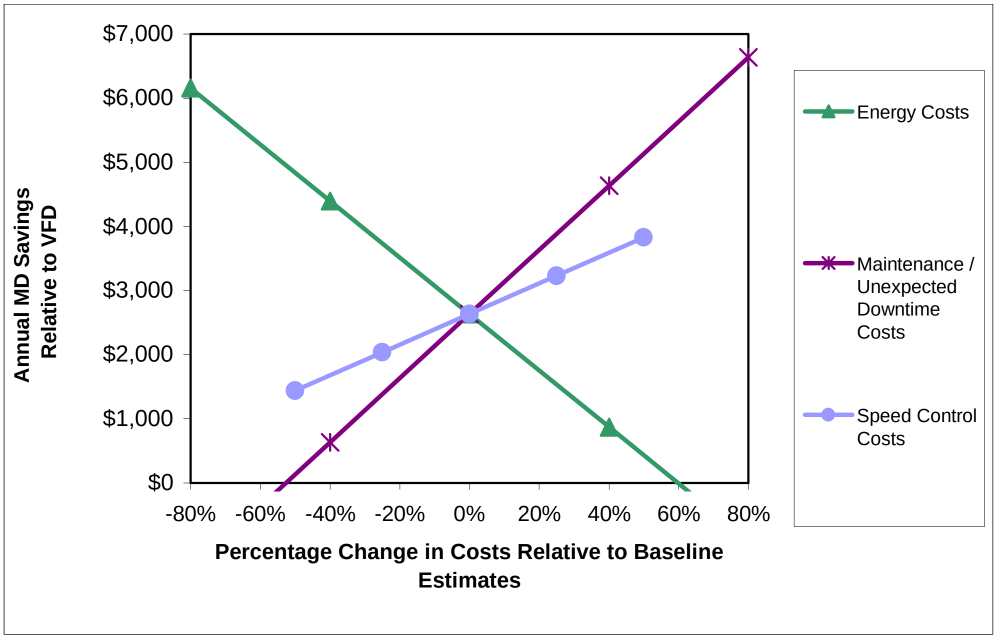
MagnaDrive savings relative to VFDs in new motor applications are not as large or robust as in retrofit applications. As shown in Figures V-12 through V-14, annualized MagnaDrive LCC savings relative to VFD begin to erode across broad ranges of input sensitivities, particularly with increases in energy prices or decreases in maintenance and downtime costs. Also, alternative scenarios (e.g., higher energy prices along with lower maintenance costs) can potentially reverse the economics.

Figure V-12
Sensitivity Analysis for MagnaDrive vs. VFD, 500 HP New Pump



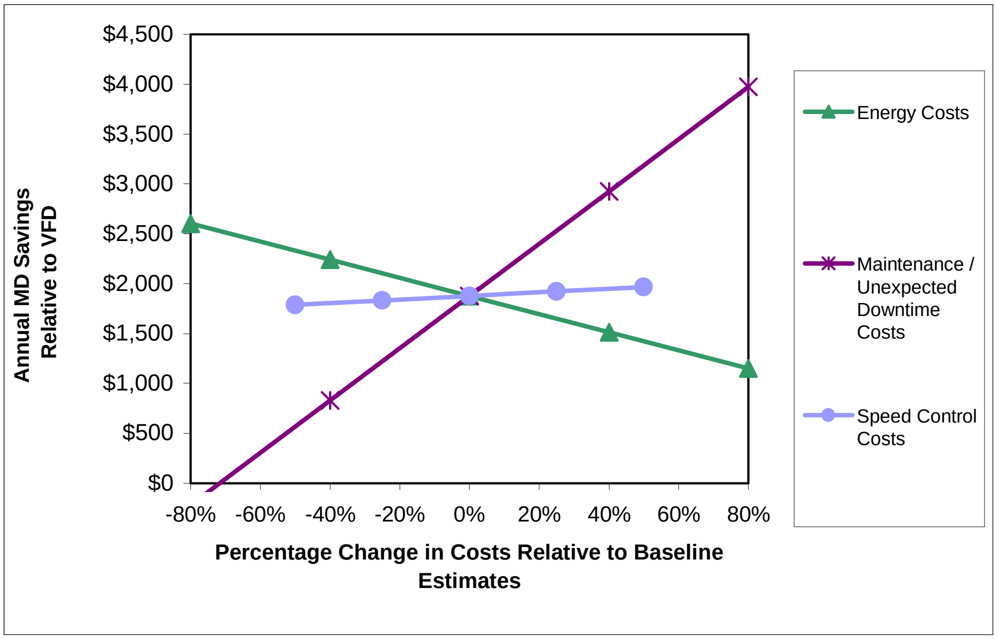
➜	Increases in energy costs will decrease the economic performance of the MagnaDrive ASD relative to the VFD.
➜	Increases in maintenance/downtime costs will increase the economic performance of the MagnaDrive ASD relative to the VFD.
➜	Increases in speed-control costs will negatively impact the economic performance of the MagnaDrive ASD relative to the VFD.

Figure V-13
Sensitivity Analysis for MagnaDrive vs. VFD, 250 HP New Fan



➜	Increases in energy costs will decrease the economic performance of the MagnaDrive ASD relative to the VFD.
➜	Increases in maintenance/downtime costs will increase the economic performance of the MagnaDrive ASD relative to the VFD.
➜	Increases in speed-control costs will positively impact the economic performance of the MagnaDrive ASD relative to the VFD.

Figure V-14
Sensitivity Analysis for MagnaDrive ASD vs. VFD,
50 HP New Pump



➜	Increases in maintenance/downtime costs will increase the economic performance of the MagnaDrive ASD relative to the VFD.
➜	Increases in energy costs will decrease the economic performance of the MagnaDrive ASD relative to the VFD.
➜	Changes in speed-control costs need to be quite large to impact the economic performance.

Although the sensitivity analysis suggests that many one-at-a-time parameter changes have little impact on the relative cost ranking, it is important to recognize that, if several variables change simultaneously, this may not hold. Thus alternative *scenarios* – where all model parameters may change – can possibly lead to different conclusions. We therefore recommend that the LCC model be applied with the unique cost parameters of a particular site to ensure that the conclusions reported here indeed hold under alternative circumstances.

Summary of LCC Findings

MagnaDrive has lower life cycle costs, faster payback, and higher IRRs compared to both VFDs and the base-motor case. This was true for all scenarios regardless of application (pump or fan), motor size, or new versus retrofit applications.

The MagnaDrive cost advantage is most pronounced for retrofit applications and larger (medium voltage) motors. This represents the greatest potential for the MagnaDrive ASD since VFD retrofit installations generally require the installation of a new motor. Plant managers and engineering consultants are generally unwilling to consider early replacement of a motor just to obtain speed control and related energy savings.

In the case of new motors, the MagnaDrive cost advantage over VFDs is much smaller. Changes in the input assumptions for MagnaDrive versus VFDs, however, can erode the savings and even reverse the economics. Indeed, we believe any head-to-head comparisons in new motor applications are inherently competitive and the results will be site specific.

The savings are most robust across a range of input sensitivities for MagnaDrive versus the base motor, less so versus VFDs. Reasonable decreases in energy prices or increases in the cost of the MagnaDrive ASD do not erode the savings from the ASD versus the base motor. Changes in the input assumptions for MagnaDrive versus VFDs, however, can potentially erode the savings and even reverse the economics.

More case studies are needed to investigate potential reduction in downtime/maintenance costs that MagnaDrive could provide. While we concur with engineering firms that VFDs should not receive a maintenance penalty, none are giving MagnaDrive a maintenance credit in the economic analyses.

VI. Summary and Recommendations

Summary of Findings

Market Update

MagnaDrive Corporation developed and implemented an aggressive marketing plan for 2001 targeting water/wastewater, pulp and paper, HVAC, and irrigation applications for the MagnaDrive ASD. The company addressed the key recommendations from the first MPER, focusing on lead generation, trade show participation, sales tools for direct and channel marketing partners, and third-party endorsements. MagnaDrive is also actively pursuing relationships with utility, commercial, and industrial conservation program managers.

While MagnaDrive is on track for a modest increase in ASD sales in 2001, the increase is far less than hoped for by the Alliance or the MagnaDrive Corporation. However, 2001 sales have been hampered by two forces outside of MagnaDrive's control: (1) widely fluctuating electricity prices, and (2) a general manufacturing slowdown that has been particularly damaging to the pulp and paper industry.

Interviews with Engineering Consultants

In an effort to better understand how engineering consultants view MagnaDrive in relation to other speed-control devices, Quantec interviewed five consultants that attended a MagnaDrive demonstration and were familiar with the technology. Some of the consultants worked at large, national consulting firms while others worked at smaller, regional firms.

Some engineers are apparently not taking the time to fully investigate the full range of speed-control options available to their customers and include new products such as the MagnaDrive ASD. They like to stay within their "comfort zones" and recommend products that they are familiar with.

Additionally, the consulting engineers do not appear to consider all of the aspects of life cycle costs in their performance calculations. None of the engineers believe that VFDs have higher O&M costs than regular motors. For example, they don't take into account MagnaDrive's non-energy benefits such as reductions in VFD-related harmonic distortion and vibration, which can reduce both downtime and O&M costs.

Development of LCC Model

The engineering interviews reinforced the need for an LCC model to quantify, in dollar terms, the economic value of both energy and non-energy benefits of the MagnaDrive ASD.

An initial Excel spreadsheet-based tool was developed for this MPER providing a variety of financial outputs: life cycle cost, simple payback, and IRR. The tool compares a VFD and a MagnaDrive ASD to a base motor and to one another. Non-energy benefits include reduced vibration, less THD, extreme soft start, easier installation, heat dissipation, lower risk of motor and shaft damage, and lower risk of product obsolescence.

LCC Findings

Given the assumptions and data available on costs and performance, the MagnaDrive ASD has lower life cycle costs, faster payback, and higher IRRs compared to both VFDs and the base-motor case regardless of application (pump or fan), motor size, or new versus retrofit applications.

The MagnaDrive cost advantage is most pronounced for retrofit applications and larger (medium voltage) motors. This represents the greatest potential for the MagnaDrive ASD since VFD retrofit installations generally require the installation of a new motor. Plant managers and engineering consultants are generally unwilling to consider early replacement of a motor just to obtain speed control and related energy savings.

In the case of new motors, the MagnaDrive cost advantage over VFDs is not as great. In a new motor installation, both the VFD and MagnaDrive ASD require a new motor purchase. The results of head-to-head comparisons in new motor applications are difficult to generalize, and will be site and application specific as some simple changes in the input assumptions can change the economics.

Conclusions and Recommendations

The key recommendations emerging from this second Market Progress Evaluation Report for the MagnaDrive ASD, Phase II are as follows:

- ➜ The lackluster performance of the MagnaDrive in terms of sales in 2001 has been caused by factors outside the Company’s control. As identified in the first MPER, there are substantial retrofit application opportunities for the MagnaDrive ASD, and the economics are very favorable in these applications. The company seems poised to increase sales markedly when the manufacturing sector of the economy recovers.

- ➜ To further support and quantify the LCC findings, MagnaDrive should collect maintenance data from each of their current installations. This will enable the Company to build the needed body of knowledge and educate the engineering community about the non-energy benefits of their ASD. While we encourage MagnaDrive to utilize the findings reported here, we also recommend that the Company not over-state the O&M savings from the ASD.
- ➜ MagnaDrive needs to continually remind decision-makers about its technology.
- ➜ MagnaDrive needs to get clients asking for the ASD in the specifications and supply more case studies to allay early adopter fears. MagnaDrive must continue to educate not only the consultants but also the decision-makers within the municipalities and private companies that are potential MagnaDrive customers.

Recommended Changes to the Alliance's Cost-Effectiveness Assumptions

Another objective of this second MPER is to review and comment on the assumptions used by the Alliance in its cost-effectiveness calculations.

Our recommended changes are as follows:

- ➜ Average energy savings used by the Alliance are conservative at 18%. Our review of the Phase 1 research conducted by OSU suggests that the savings are approximately 23% for fans and 30% for pumps. An increase to 25% in the Alliance model would be consistent with the figures used in the LCC analysis reported here.
- ➜ Non-energy benefits have not been included to date in the Alliance's cost effectiveness model. The LCC results show that non-energy benefits are sizeable, with a value of approximately 50% of the energy benefits in retrofit applications. We recommend that this figure be used in future calculations.
- ➜ The Alliance is currently using a MagnaDrive lifetime estimate of ten years, while we are using a figure of 15 years. While both figures are within the possible range for this new technology, the Alliance may want to consider increasing its lifetime to 15 years to maintain consistency with this MPER.

- ➜ Given the overall uncertainty in the manufacturing sector, we do not recommend that the Alliance revisit its sales projection assumptions at this time. The current projections are based on earlier Phase 1 research. These do not include the more optimistic market size assumptions presented in the first MPER of Phase II, which in turn pre-dates the current recession. We recommend that the Alliance revisit market size and share assumptions *after* it is clear that the Northwest manufacturing sector is emerging from the recession.

Appendix A. Interview Instrument

Discussion Guide for Engineering/Consulting Firms

Name:__________________________ Date:_______________________

Company:_______________________ Phone: ____________________

Position:________________________ Interviewer:_________________

Hello, my name is ___ and I am calling from Quantec, an energy economics consulting firm, on behalf of the Northwest Energy Efficiency Alliance. The Alliance has provided funding for the MagnaDrive, and we are assisting the Alliance and MagnaDrive staff with the on-going development of the business plan and market potential estimates. We are not selling anything; we are only conducting research. [WE ARE ONLY TALKING WITH PEOPLE AWARE OF THE ASD AND HOW IT WORKS. IF THEY ARE NOT AWARE, WE NEED TO FIND SOMEONE ELSE IN THE FIRM WHO IS AWARE OR END THE INTERVIEW.]

* * * *

Background on the engineering/consulting firm:

- ➜ Type of role the respondent has in his/her company
- ➜ Individual's background and role in the company – engineering, economics, sales, etc.?
- ➜ Familiarity with variable speed devices, motors, driven equipment

Type of engineering/consulting business and the specifics of the operation:

- ➜ Services provided
- ➜ Scope of the business – industries services (esp. WWT and P&P), number of offices (is this a local, regional, or national firm), FTEs, etc.
- ➜ Structure of local offices within the total corporate organization
- ➜ Ties to headquarters
- ➜ Is there a group or individual who is primarily responsible for energy usage and energy efficiency?

Motor system and speed-control specifics:

- ➜ What problems do you typically see with motors and motor systems?
- ➜ Do you normally recommend a specific motor repair/replacement plan? Is early retirement of motors considered?
- ➜ In motor replacement is longevity, availability, or consolidation of motor
lines important?
- ➜ Do you typically recommend VFDs or other speed-control devices in your assessments?
- ➜ How have technology improvements in the last decade influenced your analyses and thinking about speed control?
- ➜ What is your forecast of the use of VFDs and or other speed-control devices in the future (probe for details)

Reactions to the MagnaDrive ASD:

- ➜ Descriptions of the demonstration and the range of reactions across your company? Have you actually seen it in action, or is your judgement based on knowledge from written materials, discussions, etc. {probe: what do they know about it and where did they get the information}
- ➜ Assessment of the product, particularly against the conventional VFD
- ➜ Assessment of the product against the Eddy-current
- ➜ Discussion of the advantages of the MagnaDrive – shock and vibration control, simplicity, no additional space requirements, etc. – and the value of these features.
- ➜ Do you believe that the MagnaDrive, because of the shock and vibration control, would have less unexpected down time than a motor without this equipment?
- ➜ Would you expect more or less unexpected down time with a VFD compared to a motor without variable speed?

[FOR DISCUSSION: MagnaDrive MAY HAVE LESS DOWN TIME (10%) BECAUSE OF LESS WEAR AND TEAR ON THE DRIVE TRAIN AND MORE “PLAY” IN TERMS OF ALIGNMENT (LESS SHAFT BREAKAGE). VFDs MAY HAVE MORE DOWN TIME (10%) BECAUSE OF THD ISSUES AND LACK OF SPARE PARTS. DOES RESPONDENT AGREE OR DISAGREE WITH THIS?]

- ➜ Discussion of the perceived disadvantages of the MagnaDrive
- ➜ What % of variable loads would you see as applicable to MagnaDrive?
- ➜ [IF NOT MENTIONED] What are the best applications for MagnaDrive?

Factors influencing your Company's recommendations and the customer's decision to purchase a motor or speed-control device:

- ➜ Do you work in Project teams? How are final project recommendations made (i.e., who makes the final recommendation)?
- ➜ Review the factors considered in recommendations / purchases – price, energy savings, process improvement – and which ones are the most important by various use situations
- ➜ Role of energy efficiency and use of decision criteria such as payback period, life cycle costs, etc.
- ➜ Do these analyses incorporate operation and maintenance issues in addition to energy savings (mean time between motor failures, shaft breakage, vibration and alignment testing, "soft starting", the need for electric infrastructure, availability of spare parts, etc)? In other words, how comprehensive are your analyses.
- ➜ How does judgement or personal preferences factor into your recommendations, if at all?
- ➜ Have you recommended or discussed the ASD with customers? How have they reacted?
- ➜ What do you feel are the best ways to reach end-users/decision-makers in the industry with information about the MagnaDrive?
- ➜ [IF NOT MENTIONED] Are there any trade associations or publications that you find most useful?

Thank respondent for taking the time for the interview.

Appendix B. Life Cycle Cost Inputs

Cell Reference	Input Name	Notes
C8	Horsepower	In a conference call with Ken Seiden of Quantec, Phil Degens of NEEA , and Schiller Associates the decision was made to create sample motor life cycle input sheets for six scenarios. These scenarios are a 50 HP motor running a pump, a 50 HP motor running a fan, a 250 HP motor running a pump, a 250 HP motor running a fan, a 500 HP motor running a pump, and a 500 HP motor running a fan. It was also decided that these motors would be running at 1800 RPM.
C9	Annual Operating Hours	This value is computed by the worksheet and equal to Hours per shift*Number of Shifts*Number of Days worked per week*52 weeks*Duty cycle
C10	Motor Loading	This value equals the load driven by the motor. In these worksheets the load is either the movement of liquid for pumps or the movement of air for fans. The load distribution is given in % of max fluid flow required for each hour in a sixteen-hour (two shift) time period and can be seen in the worksheet labeled load distribution. It is assumed that the flow is being controlled by a throttle valve in the pump input sheets and baffles in the fan input sheets. Data from an Oregon State University (OSU) report (1) was used to correlate % flow to power used by the motor. The resulting column of data was used to calculate average motor loading.
G8	Energy Savings W/VFD	Using the same load distribution as discussed above, percent fluid flows (pff) were correlated to the power draw of a motor being controlled by a VFD. Data from the OSU report was used in the correlation. The difference between the VFD controlled motor and throttle controlled motor was divided by the max power rating of the motor to determine a percentage of energy savings at each pff. The resulting value was multiplied by the time duration of the flow level (1 hour for all flows in this load distribution). The resulting column of data was summed and then divided by the total hours the motor was on to arrive at an average energy savings. This is the value used in the input sheet. Due to time constraints, this was only done for the 50 HP pump scenario. It was assumed that the difference in motor sizes are negligible and that there is less energy saving for the fan application 50, 250, 500 HP pump VFD savings 42% 50, 250, 500 HP fan VFD savings 35%

Cell Reference	Input Name	Notes
K8	Energy Savings W/ MagnaDrive	The same procedure outlined above was used in calculating the average savings associated with motor operation using a MagnaDrive ASD. The data for both VFD and MagnaDrive are shown in the worksheet entitled Load Distribution. Due to time constraints, this was only done for the 50 HP pump scenario. It was assumed that the difference in motor sizes are negligible and that there is less energy saving for the fan application. 50, 250, 500 HP pump MagnaDrive savings 30% 50, 250, 500 HP fan MagnaDrive savings 23%
C11	Efficiency	The efficiency of a motor depends on many variables including the motor age, motor operating point in relation to full load, number and type of motor repairs, etc. The values used in these worksheets are the averages of the full load nominal efficiencies for new motors of eight motor manufacturers (2). For 500 HP motors reference (12) was used. 50 HP 91.5%, 250 HP 94.3%, 500 HP 95%
C14	Unexpected Downtime (motor alone)	Downtime is dependent on motor application, motor environment, and maintenance procedures. Larger motors usually take more time to fix and due to cost, are less likely to have backup motors. Smaller motors are more likely to be neglected. These input sheets scale unexpected downtime to motor size. It is assumed that there is no difference in the pump and fan applications.
	Model used for C14	50 HP: 20 hours/year 250 HP: 20 hours/year 500 HP: 20 hrs/year
G14	Unexpected Downtime (motor W/ VFD)	VFDs can be a source of harmonics. Harmonics can cause torque pulsation and overheating. Vibration and heat in turn can shorten motor life, by damaging bearings and insulation (2). Another issue associated with VFD control is at low motor speed there is less ventilation. This also contributes to motor overheating. On the other hand, VFDs prolong the life of a motor by reducing motor loading and offering motor soft start. Most problems associated with VFDs have known mitigations. In these input sheets it is assumed that these mitigations (listed in the capital cost section) are installed. With this in mind, it is assumed that the expected downtime of a motor with a VFD will be the same as a stand-alone motor.
	Model used for G14	G14 = Cvfd*D14 where Cvfd = 1.0
K14	Unexpected Downtime (motor W/ MagnaDrive)	Benefits of the MagnaDrive include soft start, decreased motor loading, and mechanical isolation from load to motor. For these reasons it is assumed that motors controlled by the MagnaDrive ASD will have slightly less downtime hours. As with any new product, field data is scarce and therefore models and model coefficients can only be stipulated
	Model Used for K14	K14 = Cmd*L14 where Cmd = 0.9

Cell Reference	Input Name	Notes
C15, G15, K15	Downtime Cost Model	This cost ranges from $1000 to $5000 an hour (3). In these input sheets it is assumed that the larger the motor the higher the downtime costs. In reality the cost is application specific with each application having it's own downtime costs. For example a 50 HP motor involved in a critical process might have the same downtime costs as a 500 HP motor driving a non-critical process. It is also assumed that the cost is not a function of the motor control method (throttle, VFD, MagnaDrive). Downtime Cost = $9.7 per HP (model based on very little data)
C16	Current Age	This is the age of the motor to be retrofitted with a MagnaDrive ASD or a VFD.
C17, G17, K17	Service Life Motor	The life expectancy of a motor depends on the motor's environment, load distribution, maintenance practices, quality of input power and other variables. A very general range for AC motor life expectancies is between 1000 and 200,000 hours. A typical value is 100,000 hours (6). Based on discussions with manufacturers and service firms, base 250 and 50 HP motors and drive equipment life is expected to last 15 years, VFDs 10 years, and the MagnaDrive ASD 15 years. For the 500 HP case, it is assumed that the service life is the same for the base equipment, VFD and MagnaDrive ASD at 15 year.
C18	Annual Energy Use	This value is calculated by the spreadsheet. This is a very simple model, more complicated models using power factor and load distribution may be used.
	Model Used for G17	BaseHorsePower*AnnualOperatingHours*BaseMotorLoading*0.746/BaseMotorEfficiency
K18	Annual Energy Use (VFD)	This value is calculated by the spreadsheet and is only as good as the procedure used to calculate the VFD percentage savings. In these input sheets VFD percentage savings is an average value. More precise savings can be calculated by determining VFD savings in each bin of the load distribution.
	Model Used for K18	K18= Annual Energy Use*VFD Percentage Savings
K18	Annual Energy Use (MagnaDrive)	see notes for Annual Energy Use (VFD)
	Model Used for K18	K18= Annual Energy Use*MagnaDrive Percentage Savings

<table>
<tr><th>Cell Reference</th><th>Input Name</th><th>Notes</th></tr>
<tr><td colspan="3">MOTOR MAINTENANCE SECTION</td></tr>
<tr><td colspan="2">Motor Windings</td><td></td></tr>
<tr><td colspan="2">Test Motor Windings</td><td>This test falls under the category of insulation resistance testing. There are a number of special insulation resistance tests that can reveal degradation in insulation.</td></tr>
<tr><td>D21, H21, L21</td><td>Motor Winding Tests/Year (base, VFD, MagnaDrive)</td><td>Establishing a testing schedule is an iterative process. When a motor is installed it is often necessary to prescribe somewhat frequent intervals at first, then experiment with lengthening the intervals. A general number to use on this and other preventative tests is 2 tests/year (4). Further research is required to determine if fewer or more tests are required in the cases when a MagnaDrive ASD or a Variable Frequency Drive are used to control the motor. Further research is also needed in order to determine if this number is related to motor size, fans, and pumps. It is assumed that testing period is the same for all cases.</td></tr>
<tr><td>D22, H22, L22</td><td>Motor Winding Costs/Test (base, VFD, MagnaDrive)</td><td>The cost of the test depends on the type of test and if the test is done in-house or contracted out. Further research is required in order to pin down these costs. In these input sheets it is assumed that costs scale to motor size and are the same for the three control schemes investigated (baffles/throttle, MagnaDrive, VFD) and do not depend on motor application. Based on reference (7) the average income of maintenance staff for the year 2000 was $63,365. This breaks down to $30.46/hour.
<table>
<tr><th>Motor Size</th><th>Man Hours (hrs)</th><th>Cost $/hr</th><th>Total</th></tr>
<tr><td>50</td><td>2</td><td>30.46</td><td>60.92</td></tr>
<tr><td>250</td><td>4</td><td>30.46</td><td>121.84</td></tr>
<tr><td>500</td><td>6</td><td>30.46</td><td>182.76</td></tr>
</table></td></tr>
<tr><td colspan="2">Rewind</td><td>Windings fail when insulation degrades, usually due to some combination of
over-heating, aging, and over-voltage transients (3)</td></tr>
<tr><td>D23</td><td>Rewinds/Year Base</td><td>Data supplied by reference (5) was used in the base-motor column for both pump and fan applications.
50 HP, once per 5 years 250 HP once per 7 years, 500 HP once per 10 years</td></tr>
<tr><td>H23</td><td>Rewinds/Year VFD</td><td>Based on information presented in the notes associated with Unexpected Downtime (VFD) and engineering judgment it is assumed that the interval between rewinds will stay the same in the VFD case.
50 HP, once per 5 years 250 HP once per 7 years, 500 HP once per 10 years</td></tr>
<tr><td>L23</td><td>Rewinds/Year MagnaDrive</td><td>Based on information presented in the notes associated with Unexpected Downtime (MagnaDrive) and engineering judgment it is assumed that a rewind will be required less frequently in the MagnaDrive case.
50 HP, once per 6 years 250 HP once per 8 years, 500 HP once per 11 years</td></tr>
</table>

<table>
<tr><th>Cell Reference</th><th>Input Name</th><th colspan="4">Notes</th></tr>
<tr><td>D24, H24, L24</td><td>Rewind Cost/Repair (base, VFD, MagnaDrive)</td><td colspan="4">Cost data from Table A-1 in reference (2) and reference (5) Rewind costs are assumed to be the same for the three control scenarios and not to differ between the pump and fan applications.
50 HP $800; 250 HP $2,500 ; 500 HP $6,000</td></tr>
<tr><td colspan="2">Motor Bearings and Seals (MBS)</td><td colspan="4"></td></tr>
<tr><td colspan="2">MBS Preventative Maintenance (PM)</td><td colspan="4">MBS preventive maintenance includes checking bearing temperature, oiling bearings, and a thorough visual inspection.</td></tr>
<tr><td>D26, H26, L26</td><td>MBS PMs/year (base, VFD, MagnaDrive)</td><td colspan="4">See notes on tests/year (D21, H21, L21) in motor windings section. In addition, according to reference (6) it is typical for greases to break down after 10,000 hours so 2 tests per a year is a conservative interval.</td></tr>
<tr><td rowspan="3">D27, H27, L27</td><td rowspan="3">MBS Cost/PM (base, VFD, MagnaDrive)</td><td colspan="4">See notes on cost/year (D22, H22, L22) in motor windings section (note: all values stipulated)</td></tr>
<tr><td>Motor Size</td><td>Man Hours (hrs)</td><td>Cost $/hr</td><td>Total</td></tr>
<tr><td>50
250
500</td><td>1
2
3</td><td>30.46
30.46
30.46</td><td>30.46
60.92
91.38</td></tr>
<tr><td></td><td>MBS Repair</td><td colspan="4">The life of the bearings is dependent on many variables including vibration, alignment, motor cleanliness, and greasing frequency.</td></tr>
<tr><td>D28</td><td>MBS Repairs/Year (Base)</td><td colspan="4">According to resource (6) the typical life of bearings is 40,000 hours. In applications where there is a lot of stress (heat or mechanical) bearing life can drop to 14,000 hours. In favorable conditions bearings can last up to 250,000 hours. It is assumed that there is no difference in the two application considered.</td></tr>
<tr><td></td><td>Model Used for D28</td><td colspan="4">Bearings and seals repairs/year = Annual Operating Hours/40000</td></tr>
<tr><td>H28</td><td>MBS Repairs/Year VFD</td><td colspan="4">Based on information presented in the notes associated with Unexpected Downtime (VFD) and engineering judgment it is assumed that the interval between bearing repairs will stay the same in the VFD case.</td></tr>
<tr><td></td><td>Model Used for H28</td><td colspan="4">Bearings and seals repairs/year (VFD) = Annual Operating Hours/40000</td></tr>
</table>

<table>
<tr><th>Cell Reference</th><th>Input Name</th><th>Notes</th></tr>
<tr><td>L28</td><td>MBS Repairs/Year MagnaDrive</td><td>According to reference (8) 45% to 80% of bearing and seal failure is due to misalignment. According to MagnaDrive Corp. “mechanical isolation of motor and load enables a certain tolerance for misalignment of motor and load shafts, while providing a cushion for the motor to vibrations and disturbances originating at the load. Based on the above statements and information presented in the notes associated with Unexpected Downtime (MagnaDrive) it is assumed that bearing life is extended in the MagnaDrive case.</td></tr>
<tr><td></td><td>Model Used for L28</td><td>Bearings and seals repairs/year (MagnaDrive) = Annual Operating Hours/60000</td></tr>
<tr><td>D29, H29, L29</td><td>MBS cost/Repair (base, MagnaDrive, VFD)</td><td>Cost per repair is assumed to stay the same in the three motor control scenarios and in both pump and fan applications. Values for bearing replacement were obtained from reference (5).
50 HP $450 ; 250 HP $800; 500 HP $1250</td></tr>
<tr><td>Electrical Testing</td><td></td><td>Testing includes electrical monitoring of voltage and current, power factor, phase balance line harmonics, current and voltage balance, as well as visual inspection of fuses and connections etc.</td></tr>
<tr><td>D31, L31</td><td>Electrical Tests/Year (base, MagnaDrive)</td><td>It is assumed that this interval is the same for the three motor sizes and does not vary in the two applications and between the MagnaDrive and base motor. The assumed interval is 1 test per year in all base-motor and MagnaDrive scenarios.</td></tr>
<tr><td>H31</td><td>Electrical Tests/Year (VFD)</td><td>VFDs have harmonics that may be damaging to electrical components and it is assumed to require more testing: Two tests per year.</td></tr>
<tr><td>D32, H32, L32</td><td>Electrical Cost/Test (Base, MagnaDrive, VFD)</td><td>Cost is dependent on what in the electrical system has malfunctioned and has a wide range. It is assumed that there is no difference in cost per test in regards to the three motor sizes or the two applications considered. It is also assumed that it will take twice as long to complete the test for motors with VFD control.
<table>
<tr><th></th><th>man hours (hrs)</th><th>cost ($/hour)</th><th>Total ($)</th></tr>
<tr><td>Base and MagnaDrive</td><td>1</td><td>30.46</td><td>30.46</td></tr>
<tr><td>VFD</td><td>2</td><td>30.46</td><td>60.92</td></tr>
</table>
<table>
<tr><th></th><th>Man Hours (hrs)</th><th>Cost $/hr</th><th>Total</th></tr>
<tr><td>Base and MagnaDrive</td><td>1</td><td>30.46</td><td>30.46</td></tr>
<tr><td>VFD</td><td>2</td><td>30.46</td><td>60.92</td></tr>
</table></td></tr>
</table>

<table>
<tr><th>Cell Reference</th><th>Input Name</th><th colspan="4">Notes</th></tr>
<tr><td>D33, H33, L33</td><td>Electrical Repairs/Year (base, MagnaDrive, VFD)</td><td colspan="4">It is assumed that this interval is the same for the three motor sizes and does not vary in the two applications considered, nor does it vary between the MagnaDrive and the base-motor cases. The interval is assumed to be once every 5 years in the base-motor, VFD, and MagnaDrive scenarios.</td></tr>
<tr><td rowspan="3">D34, H34, L34</td><td rowspan="3">Electrical cost/repair (Base, MagnaDrive, VFD)</td><td colspan="4">Cost is dependent on what in the electrical system has malfunctioned and has a wide range. Costs scale to motor size and are the same in the two applications considered and in the MagnaDrive and base-motor scenarios. It is also assumed that repairs involving VFD will be more expensive and time consuming because of the added electrical complexity.</td></tr>
<tr><td>MagnaDrive</td><td>Cost</td><td>VFD</td><td>Cost</td></tr>
<tr><td>50 HP
250 HP
500 HP</td><td>$200
$400
$600</td><td>50 HP
250 HP
500 HP</td><td>$5000
$5000
$7500</td></tr>
<tr><td colspan="6">Thermal Testing</td></tr>
<tr><td>D36, L36</td><td>Thermal Tests/Year (base, MagnaDrive)</td><td colspan="4">It is assumed that this interval is the same for the three motor sizes and does not vary in the two applications considered. Also does not vary between the MagnaDrive and the base motor. The assumed interval is 2 tests per year in all base-motor and MagnaDrive scenarios.</td></tr>
<tr><td>H36</td><td>Thermal Tests/Year (VFD)</td><td colspan="4">Changing harmonics, over-voltage, and poor cooling at low speeds cause motor overheating. These VFD drawbacks warrant increased thermal testing. It is assumed that thermal testing will be increased to three times per a year in the VFD case.</td></tr>
<tr><td>D37, H37, L37</td><td>Thermal Cost/Test (base, MagnaDrive, VFD)</td><td colspan="4">The cost per test is assumed not to vary with motor size, application, or motor control strategy
2 man-hours*30.43$/hr= $60.86 using infrared temperature sensor.</td></tr>
<tr><td colspan="2">Vibration Testing</td><td colspan="4">A change in vibration often signals a bearing problem. It can also signal other problems like load imbalance, bent shaft, rotor damage, increase or change in line harmonics, and coupling misalignment. No repair input is shown in this category because most repairs associated with vibration are included in other categories (bearings, electrical, etc.)</td></tr>
<tr><td>D39, L39</td><td>Vibration Tests/Year (base, MagnaDrive)</td><td colspan="4">It is assumed that this interval is the same for the three motor sizes and does not vary in the two applications considered. The interval also does not vary between the MagnaDrive and the base motor. The assumed interval is 2 tests per year in all base-motor and MagnaDrive scenarios.</td></tr>
</table>

Cell Reference	Input Name	Notes			
H39	Vibration Tests/Year (VFD)	An increase or change in harmonics and load imbalance can cause vibration. Thus, motors with VFDs should be checked more frequently: The interval assumed is 3 tests per year.			
D40, L40, H40	Vibration Cost/Test (base, MagnaDrive, VFD)	The cost is assumed to be the same in the two applications and the three motor control scenarios. According to reference (5) vibration tests typically take 3 hours. This time includes travel, data acquisition, and a report. Two people are sent for motors larger then 300 HP. For motors smaller than 300 HP, one person is sent. Pay rate is $75/hr per person.			
		Motor Size	***Man Hours (hrs)***	***Cost $/hr***	***Total***
		50	3	75	225
		250	3	75	225
		500	6	75	450
Motor Cleaning		Cleaning the motor casing and the ventilation filters is important because the operating temperature increases as dust and dirt accumulate. Cooler motors operate more efficiently and have longer lifetimes.			
D42, H42, L42	Cleanings/Year (base, MagnaDrive, VFD)	This depends on the environment of the motor and type of motor among other things. The dirtier the environment the more often cleanings should occur. Reference (4) suggests that a typical interval for cleaning is twice a year. It is assumed that the cleaning period does not vary with motor size or the two applications considered.			
D43, H43, L43	Cost/Cleaning (base, MagnaDrive, VFD)	Surface dirt can be removed by various means, depending on its composition. Methods for dirt removal include compressed air, vacuum cleaning and direct wipes down with rags and brushes. (4). It is assumed that cleaning costs scale with motor size as follows.			
		Motor Size	***Man Hours (hrs)***	***Cost $/hr***	***Total***
		50	1	30.46	30.46
		250	2	30.46	60.92
		500	3	10.46	91.38

<table>
<tr><th>Cell Reference</th><th>Input Name</th><th colspan="8">Notes</th></tr>
<tr><th colspan="10">Drive Train Maintenance</th></tr>
<tr><td colspan="2">Shaft Alignment</td><td colspan="8"></td></tr>
<tr><td>D46</td><td>Alignments/ Year (BASE)</td><td colspan="8">It is assumed that the number of alignments is not a function of motor size or application
Shaft alignment should be performed every 2000 to 4000 hours for the first two years. If no change in alignment is witnessed after this period of time monitoring should continue every 3-5 years.
The above averages out to an alignment every two years over a twenty year life cycle.</td></tr>
<tr><td>H46</td><td>Alignments/Year VFD</td><td colspan="8">Based on information presented in the notes associated with Unexpected Downtime (VFD) and engineering judgment it is assumed that the interval between alignments will stay the same with VFDs. It is assumed an alignment will be needed once every two years.</td></tr>
<tr><td>L46</td><td>Alignments/Year MagnaDrive</td><td colspan="8">Reference (10) suggests that the MagnaDrive can handle “gross misalignment” in the shafts. Therefore alignments should occur less frequently with the MagnaDrive ASD. It is assumed an alignment will be required once every 4 years.</td></tr>
<tr><td rowspan="3">C47, H47, L47</td><td rowspan="3">Cost/Alignment</td><td colspan="8">It is assumed that alignment costs scale with motor size stay the same in the pump and fan applications. It is also assumed that MagnaDrive alignment are less expensive because the ASD allows for greater misalignment .The range of contract service rates for alignment are $45 to $145/ hour per person (11)</td></tr>
<tr><td>VFD base motor size</td><td>man hours (hrs)</td><td>Cost ($/hour)</i></td><td><i>Total ($)</td><td>MagnaDrive motor size</td><td>Man hours (hrs)</td><td>Cost ($/hour)</i></td><td><b><i>Total ($)</td></tr>
<tr><td>50
250
500</td><td>2
4
6</td><td>80
80
80</td><td>160
320
480</td><td>50
250
500</td><td>1
3
5</td><td>80
80
80</td><td>80
250
400</td></tr>
<tr><td colspan="2">Couplings</td><td colspan="8">Most maintenance associated with couplings has to do with proper alignment (2). Most fan applications have belts rather than couplings so the values were zeroed out in all the fan application scenarios.</td></tr>
<tr><td>D49, H49</td><td>Couplings Tests/Year (Base, VFD)</td><td colspan="8">These tests are covered in the alignment section. So all values were set to zero.</td></tr>
<tr><td>L49</td><td>Couplings Tests/Year (MagnaDrive)</td><td colspan="8">The MagnaDrive ASD is a new product and consequently, unpredictable problems may arise. Yet, this is likely only in the first install, therefore over the model life it is assumed to be zero.</td></tr>
<tr><td>D50, H50</td><td>Couplings Costs/Test (Base, VFD)</td><td colspan="8">Most of the cost associated with couplings maintenance is absorbed in the alignment section of the input sheet. Consequently, the cost for the tests is zeroed out for all cases.</td></tr>
</table>

<table>
<tr><th>Cell Reference</th><th>Input Name</th><th>Notes</th></tr>
<tr><td>L50</td><td>Couplings Costs/Test (MagnaDrive)</td><td>It is assumed that testing costs scale with motor size and don't vary based on application

50 HP $50 250 HP $100 300 HP $150</td></tr>
<tr><td>D51, H51</td><td>Coupling Repairs/Year (Base, VFD)</td><td>Reference (6) suggests a typical ASD life of 75,000 hours with a range of 25,000 to 333,000 hours. It is assumed that this is valid for all motor sizes and in the base-motor and the VFD scenarios.</td></tr>
<tr><td></td><td>Model Used for D51, H51</td><td>ASD repairs/year (base and vfd) = annual operating hours/75,000. This equates to approximately one repair every 15 years.</td></tr>
<tr><td>L51</td><td>Coupling Repairs/year (MagnaDrive)</td><td>MagnaDrive engineering staff encourage customers to follow a preventive maintenance program to ensure that each ASD lasts 15 years or more. This includes replacing the cam follower assemblies and pivot link assemblies.</td></tr>
<tr><td></td><td>Model Used for L51</td><td>Once every five years per MagnaDrive staff recommendations.</td></tr>
<tr><td>D52, H52, L52</td><td>Coupling Cost/Repair (base, VFD, MagnaDrive)</td><td>The MagnaDrive ASD is a more complicated and expensive piece of equipment than most typical industrial couplings. It is assumed that the cost of repairing the MagnaDrive ASD will be greater than the cost of repairing an ordinary coupling. It is also assumed that cost of repair for all couplings scales to motor size.
<table>
<tr><th>VFD / base motor size</th><th>man hours (hrs)</th><th>Cost ($/hour)</i></th><th><i>Total includes materials ($)</th><th>MagnaDrive motor size</th><th>Total Includes material ($)</th></tr>
<tr><td>50</td><td>2</td><td>30</td><td>$200</td><td>50</td><td>$ 2000</td></tr>
<tr><td>250</td><td>4</td><td>30</td><td>$400</td><td>250</td><td>$ 2500</td></tr>
<tr><td>500</td><td>6</td><td>30</td><td>$600</td><td>500</td><td>$3000</td></tr>
</table></td></tr>
</table>

<table>
<tr><th>Cell Reference</th><th>Input Name</th><th colspan="4">Notes</th></tr>
<tr><td colspan="2">Belts</td><td colspan="4">The user of this input sheet may not have a belt driven system. In this case the user should enter zero in all inputs associated with belts. All inputs associated with belts for the pump applications considered have been set to zero because pumps are rarely driven by belts.

“V-belts run longer and perform better if they are given the proper care and attention during installation, and in particular, during the following 48-hour running-in period. This is a most critical time for V-belts, especially if they are to last for a few years. During this run-in period, the initial stretch is taken out of the belt. Also, the soft rubber surface of the belt’s outer envelope is abraded away, and the belt settles deeper in the groove of the sheave. This causes the belt to run slack. At this point, the slack on the new belts must be taken up to avoid considerable slippage, frictional burning, and other irreparable damage. It is very important that the belts are checked often over the first few days of operation and are adjusted according to the correct tension until all signs of stretching have been eliminated. This practice will eliminate early damage and promote longer belt lives.” (13)</td></tr>
<tr><td>D54, H54, L54</td><td>Belt Tests/Year (Base, VFD, MagnaDrive)</td><td colspan="4">Belt testing is unevenly distributed over the life of the belt, with the majority of tests taking place immediately after installation. Assume six tests in the first two weeks after installation and annual tests there after. This averages out to about 2 tests every year over the life of the belt. (see notes on belt repairs/year for average life of belts). Assume testing period is not a function of motor size, application, or motor control.</td></tr>
<tr><td rowspan="3">D55, H55</td><td rowspan="3">Belt Cost/Test (Base, VFD)</td><td colspan="4">Assume that cost of tests is not a function of application, or motor control scenario and that it scales with motor size as follows</td></tr>
<tr><td>VFD base motor size</td><td>man hours (hrs)</td><td>Cost ($/hour)</i></td><td><b><i>Total ($)</td></tr>
<tr><td>50
250
500</td><td>0.5
1
1.5</td><td>30
30
30</td><td>15
30
45</td></tr>
<tr><td>L55</td><td>Belt Cost/ Test (MagnaDrive)</td><td colspan="4">See notes for Tests/year MagnaDrive (L54)</td></tr>
<tr><td>D56</td><td>Belt Repairs/ Year base</td><td colspan="4">According to reference (5) the range of life hours for belts is between 9,000 and 91,000 hours with a typical value of 30,000 hours. Assume that in both pump and fan applications and for all motor sizes the drive belts will last 30,000 hours.</td></tr>
<tr><td></td><td>Model Used for D56</td><td colspan="4">Repairs/year base = annual operating hours/30,000</td></tr>
</table>

Cell Reference	Input Name	Notes			
H56, L56	Belt Repairs/Year VFD	Due to the soft start of most VFDs and MagnaDrive it is assumed that the typical life of the belt will be extended. Assume a typical life of 35,000 hours			
	Model Used for H56	Repairs/year base = annual operating hours/35,000			
D57, H57, L57	Belt Cost/Repair	Assume that this cost is not a function of motor control scenario or application and that cost scales with motor size			
		Motor size	***man hours (hrs)***	***Cost ($/hour)***	***Total ($)***
		50	4	30	120
		250	6	30	180
		500	8	30	240
Baffles/Vanes/Throttle (BVT)		When a VFD or a MagnaDrive is introduced into applications there is no longer a need for these types of mechanical controls. Consequently, there are no inputs for VFDs and MagnaDrives associated with this category. There are many ways to control flow. Maintenance requirements are going to be dependent on the specific type of flow control used in an application.			
D60	BVT Tests/Year	Assume two tests per year			
D61	BVT Cost/test	In these input sheets it is assumed that the cost of tests don't vary with either motor size or application. It is also assumed the a maintenance person spends two hours, twice a year performing tests associated with mechanical flow control devices. (2 hours* $30/ hr = $60).			
D62	BVT Repairs/year	According to reference (5), the equipment associated with mechanical flow control such as valves have a typical life expectancy of 40,000 hours. A range to use for these devices is between 3,000 and 80,000 hours depending on application.			
	Model Used for D62	Baffles/Vanes/Throttle Repairs/year = annual operating hours/40,000			
D63	BVT Cost/Repair	In these input sheets it is assumed that cost of repair will scale to motor size.			
		VFD base motor size	***man hours (hrs)***	***Cost ($/hour)***	***Total ($)***
		50	8	30	240
		250	12	30	360
		500	16	30	480

Cell Reference	Input Name	Notes
		CAPITAL COSTS
C65	Motor 50 HP 250 HP 500 HP	The input sheet can be used to compare capital costs for planned installation of all components in the process control system or installation of a VFD or MagnaDrive onto an existing system. In the case where the system is not in place, the user should include the price of the motor to be used. The following are prices for 50 HP motors. There is a wide range depending on the type of motor to be used. Reference (12): $4157, TEFC, efficient, 1800 RPM, list price Reference (14): $2250. NEMA class B, open drip proof, 1800 RPM Reference (16): 50 HP, NEMA design A and B, open drip proof, average price = $2909 (1800 RPM, e-motors), $2110 (1800 RPM, standard) 50 HP, NEMA design A and B, TEFC, average price =$4069(1800RPM, e-motors), $3707 (1800 RPM, standard), $4798(1800 RPM, e-motors), $3114 (1800 RPM, standard) For 50 HP motors $3000 value was used. Reference (12): $28907, NEMA, class B, 1800 RPM list price Reference (16): 250 HP, open drip proof, average price =$11241 (1800 RPM) 250 HP, TEFC, average price=$17975 (1800 RPM) For 250 HP motors $17,000 value was used Reference (12): $32,127, Type 1 enclosure, Ball Bearing, High efficiency, 1800 RPM, 500 HP list price Reference (16): 500 HP, open drip proof, average price =$23294 (1800 RPM) 500 HP, TEFC, average price = $39122 (1800 RPM) For 500 HP motors $32,000 value was used

Cell Reference	Input Name	Notes
C66	Motor starters	(Reference 10): 50 HP $1,000 (Reference 17): 50-100 HP $780 For 50 HP motor starters $900 value was used (Reference 17): 250-500 HP $6200 Extrapolation of reference (10) 250 HP motor starter $5000, For 250 HP motor starters $5750 value was used (Reference 17): 250-500 HP $6200 low voltage Extrapolation of reference (10) 500 HP motor $10000 For 500 HP motor starters $7500 value was used with a 100% markup for Medium voltage applications
C67	Flow control equipment	Equipment such as valves, baffles, etc. Depends on application. Values assumed at 50 HP $1000, 250 HP $2000, 500 HP $3000
C68	Couplings or Belts	Same as repair cost.
C69	Other	Any capital expense that does not fall into the categories above
C70	Installation	Depends on application
C74	Salvage value	Assumed to be zero
VFD		According to reference (18) hardware costs can vary widely depending on features and ruggedness. Total installed cost per horsepower varies widely as well, primarily due to the wide variety of features available. According to reference (15) many of the newer VFD come with " fuses, line reactors, and other elements". However, these features come with a price tag. Reference 18 gives the following price ranges for VFD hardware alone. 50 HP: $75/HP-$150/HP or $3750 to $7500 250 HP: $55/HP to $120/HP or $13,750 to $30,000 500 HP: $53/HP to $105/HP or $26500 to $52500
G65	Motor	See notes for C65. Reference (22) suggests that in most retrofit cases the old motor can not be used. The user of the input sheets might consider the price of a new motor when assessing VFD capital costs.

Cell Reference	Input Name	Notes
G66	50 HP VFD	50 HP VFD (Reference 18) $120/HP for 50 HP or $6000 (Reference 19) 50 HP, NEMA 12 enclosure, Variable Torque, 1 Disconnect $13,513 (Reference 20) 50 HP $5100 (Reference 21) 50 HP base price $8554, w/ line reactor add $3,114, (Reference 23) 50 HP NEMA 1 $5,695 (Reference 24) 50 HP configured package (w/o installation): $14,505 (includes 3% line reactor, DC link reactor, RFI input filter, bypass option, input contactor, output contactor) For 50 HP VFD $9,000 value was used
	250 HP VFD	250 HP VFD (Reference 18) $88/HP for 250 HP or $22000 (Reference 19) 250 HP, NEMA 12 enclosure, Variable Torque, 1 Disconnect $42,356 (Reference 20) 250 HP $17700 (Reference 21) 250 HP base price $28,711 (Reference 23) 250 HP base price $21,750 (Reference 24) 250 HP configured package (w/o installation) $49,394 (includes 3% line reactor, DC link reactor, RFI input filter, bypass option, input contactor, output contactor) For 250 HP VFD $29,000 value was used
	500 HP VFD	500 HP VFD (Reference 18) $100/HP for 500 HP or $50,000 (low voltage) (Reference 20) 500 HP $42600, 80% - 100% increase for Medium Voltage: $76,680 (Reference (15) suggests that installed cost for intermediate voltage drives is $150/HP @ 500 HP this would be $75,000 For 500 HP VFD $100,000 value was used (medium voltage) based on manufacturer quotes, web sites, and discussions with manufacturer representatives

Cell Reference	Input Name	Notes
G67	RFI Filter	**50 HP**: (Reference 23) $2,179 (included in accessories) **250 HP**: (Reference 23) $7,810 (included in accessories) Not needed for MV motors.
G68	Line Reactor	**50 HP**: (Reference 21): $1,872; (Reference 25): $816 (included in accessories) **250 HP:** (Reference 21): $13,232; (Reference 23): $2,086 (included in accessories) Not needed for MV motors
G69	Panel and Accessories	(Reference 21) 50 HP Accessories include Input line fuses ($498), manual bypass ($1714), main input disconnect ($781) output contactor ($630) **50 HP:** Total = $3,623; (Reference 21) 250 HP Accessories include Input line fuses (included), manual bypass ($6100), main input disconnect ($2407) output contactor ($3872) **250 HP**:Total = $12,379 MV motors: all accessories included VFD price.
G70	Spare Cards	Assumed to be part of accessories and/or VFD price for one set of repairs. Part of electrical repair costs after first set of spare cards is used.
G71	Couplings or Belts	Same as repair cost.
G72	Other	Any capital expense that does not fall into the categories above
G73	Installation	According to reference (18) the total cost of installation labor and materials is 50 HP: $105/HP to $235/HP or $5250 to $11750 250 HP: $55/HP to $120/HP or $13750 to $30000 500 HP $75/HP to $145/HP or $37500 to $72500 Reference (15) suggests $150/HP for medium voltage applications or $75000 total installed price. It also states that installation cost can run anywhere from 15% to 100% of the equipment costs depending on application. 25% of equipment costs was assumed for these worksheets.
G74	Salvage Value	Assumed to equal zero
MagnaDrive		Values from reference (10)
K65	Motor	See notes for C65
K66	MagnaDrive ASD	50 HP $10,000, 250 HP $23,000, 500 HP $50,000 per discussions with MagnaDrive.

Cell Reference	Input Name	Notes
K67	PCA	50 HP $3,000, 250 HP $3,000, 500 HP $3,000
K68	Motor Starter	See notes for C66
K69	Other	Any capital expense that does not fall into the categories above
K70	Installation	50 HP $2,200, 250 HP $4,000, 500 HP $4,000 per discussions with MagnaDrive.
K74	Salvage Value	Assumed to equal zero

References

(1) "Product Testing: Magna Drive, Report #1" Prepared by Motor Systems Resource Facility.

(2) Nadel, Shepard, Greenberg, and Katz, " Energy-Efficient Motor Systems" American Council for Energy-Efficient Economy, 1991.

(3) Based on interviews conducted by Schiller Associates of personnel in the Pulp and Paper and Wastewater Management industries.

(4) McCoy G.A. and Douglass J.G. "Energy Management For Motor Driven Systems," Department of Energy's Motor Challenge Program.

(5) Phone interview of a sales rep at Littlejohn-Reuland Corp.

(6) Weibull Database (see www.barringer1.com/wdbase.htm)

(7) R. Baldwin "1999 Maintenance Salaries" Maintenance Technology Magazine Dec. 1999.

(8) Richard L. Nailen, "Managing Motors," Barks Publications Inc., 1991, Chicago, IL.

(9) www.turvac.com

(10) www.magnadrive.com

(11) V. Wowk "Specifying Shaft Alignment" Maintenance Technology Magazine, May 2000.

(12) U.S. Electrical Motors Catalog.

(13) www.maintenanceresources.com; "Proper Installation and Maintenance Can Prolong the Life of V-Belts" by John C. Robertson.

(14) RSMeans Costworks 2000 software.

(15) Easton Consultants "Market Research Report: Variable Frequency Drives" Easton Consultants, Inc. June, 2000.

(16) Motor Master +3.02 software, 1999 Version.

(17) Seimens online catalog.

(18) Costs were estimated by interpolating the figures 11-2 and 11-3 in E-source Atlas: DrivePower, 1999. The data is actually adapted from BPA ASD guidebook.

(19) Quote from Alameda Electrical Distributors, Inc.

(20) Phone Interview with Thomas Keehbauch, Xcel Energy.

(21) Reliance Electric, reliance vfd prepack prices.pdf, Feb 2001.

(22) Plant Engineering Magazine, " AC Motor/Drive/Load Compatibility Evaluation" 1996.

(23) GE Fuji Drives USA www.geindustrial.com/industrialsystems/drives Standard Drives Buyer's Guide.

(24) GE Fuji Drives USA www.geindustrial.com/industrialsystems/drives Configured Drives Program Pricing Guide.

(25) GE Fuji Drives USA www.geindustrial.com/industrialsystems/drives Options and Accessories.