FEASIBILITY ANALYSIS OF AN AUTOMATED MUSHROOM HARVESTING SYSTEM

by

AREG AZOYAN

(Under the direction of Michael Wetzstein)

ABSTRACT

Harvesting is the only step in commercial mushroom cultivation that is not yet mechanized. UK based Silsoe Research Institute developed and successfully tested an automated mushroom harvesting robot suitable for agaricus mushroom production. The aim of this thesis is to provide an analysis of the advantages and disadvantages of automated mushroom harvesting versus manual, and discuss economic feasibility of adopting this new technology. Different scenarios for manual labor wage rate, mushroom harvester working hours, and the discount rate were examined. The results reveal that in most cases it is economically feasible to use robots in mushroom harvesting process.

INDEX WORDS: Agaricus Mushroom, Automated Mushroom Harvesting, Manual Harvesting, Mushroom Cultivation, Net Present Value

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Dedicated to my Parents

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TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

Background

Within the U.S., mushrooms are considered gourmet products not only for their unique taste, but also for their high nutritional value. Households substitute mushrooms for high quality meat and they contain many microelements necessary for human health. Currently, the United States produces annually over than 800 million pounds of fresh mushrooms and imports over 170 million pounds of processed mushrooms, primarily from Asia (India, Indonesia, China). In terms of mushroom types, agaricus mushrooms are the most widely consumed mushrooms around the world.

The mushroom industry is labor intensive and it is hard for the U.S. to compete with Asian competitors due to significant difference in labor wages. In an effort to remain competitive U.S. production has shifted toward mechanized production. Currently, the only stage in mushroom production technology that is not mechanized is the harvesting process. All producers within the U.S. are harvesting mushrooms manually. In accordance with the Tinselltone recruiting company, which has supplied pickers for the mushroom industry for over ten years, the current average wage rate for a picker in the U.S. is $6.50 per/hour (Aviv 2004). Given that the average mushroom picker can harvest efficiently about 30 pounds of mid size mushrooms per hour (Lou Summerfield, 2004), then on average the picking cost is approximately $0.22 per pound or around 20% of the wholesale price. Industrialized countries in Western Europe are also facing similar high harvesting cost in the mushroom industry. A study, conducted in 1997, indicated that labor represents approximately 46% of the costs of mushroom production for the fresh market in the EU (Farrar J., 1999). The vast majority of this labor is spent on the harvest, because all other stages are mechanized.

In 1993 the European Union provided funding to the UK based Silsoe Research Institute to develop an automatic mushroom harvester. A group of bioengineers developed a robotic harvesting system, which is capable of automatically locating, sizing, selecting, picking, trimming, conveying, and transferring mushrooms to boxes.

Since 1995 performance tests for a pilot harvester were conducted at two separate sites: at Horticulture Research Institute, Wellesbourne, Great Britain and at a commercial mushroom farm in Netherlands. Over the combined sites the robot made 2,975 picking attempts of which 2,427 were successful, (i.e. over an 80% picking efficiency rate).

During the commercial farm trials, 75.9% of the crop was harvested automatically and the levels of mushroom bruising and marks or damage to the robotically harvested crop were significantly lower than those with manual picking. The overall success of the farm trials clearly demonstrates the technology for commercial harvesting of mushrooms by a robot is now technologically feasible (Reed, 2001).

The question of interest now turns to the economic feasibility of a robot. The U.S. agaricus mushroom industry is facing problems related to the organization and implementation of manual mushroom picking. Among those are health and safety issues, frequent complaints of labor unions regarding low wages, which can turn into serious conflicts between management and labor personnel, permanent labor flow, labor efficiency, and difficulties in organizing manual picking of mushrooms due to the specific lifecycle of fungi, all represent labor problems. However, the picking speed of the single end-effector pilot harvester is only about nine mushrooms per minute compared with the speed of manual pickers which is twice as fast. (Reed, 2001).

Also the use of robots in commercial farms will not totally eliminate the demand for labor. Instead it is estimated the robots can decrease harvesting labor requirements by approximately 75% (Reed, 2001). When a crop has a very high density, robots can not operate effectively and will damage neighboring mushrooms. For this reason labor should first pick the mushrooms from the high density area and leave the rest of the harvest to a robot.

Objectives

The objectives of this thesis are: (1) to examine the economic feasibility of adopting harvesting robots, and (2) to compare the advantages and problems for both manual and automated harvesting systems. Specifically, the characteristics of the U.S. mushroom are first discussed. Based on these characteristics, the current manual harvesting of mushrooms within the U.S. is outlined. Manual harvesting is then compared with an automated harvesting system based on prices provided by several companies specialized in manufacturing mushroom equipment.

For developing the feasibility of the robots the production process is required. There is currently no standard production process. It depends on how the farm is organized. Thus, for a given price of a harvesting robot, it should be feasible for one producer to adopt the new technology, but wrong for another.

Currently there is no commercial manufacturing of harvesting robots and limited information exists on their feasibility so only estimates are used for the analysis. An economic comparison of the cost saving in labor with the initial capital expenditure for a robot would aid in determining the economic feasibility of harvesting robots and their likely adopting within the industry. Based on the information regarding average hourly wage of mushroom pickers, the breakeven point for the new technology will be calculated and then the maximal price for each unit of the mushroom harvesting robot will be determined, below which it is economically feasible for a mushroom grower to switch to the new technology.

This analysis will aid mushroom producers in their decisions to adopt harvesters. This study is designed to provide the necessary tools for calculating what are the possible costs and returns from adopting the new technology.

Organization

Chapter 2 includes a discussion on the agaricus cultivation techniques and fungi lifecycle. This discussion outlines problems with manual harvesting systems based on current cultivation techniques and fungi. Chapter 3 provides brief overview of the current situation in U.S. mushroom industry, trends and perspectives, and the agaricus mushroom international trade related issues . The manual and automated harvesting systems, their advantages and disadvantages are also discussed within Chapter 3. The theory underlay the economic feasibility analysis of automated mushroom systems is developed in Chapter 4. In chapter 5 the trend construction and test for stationarity of mushroom prices are performed. Based on the actual data, the present values of robots are calculated in Chapter 6, using different scenarios for hourly wage rates and discount rates. Tax incentives for firms investing in new technology will also be considered. Present value analysis indicates the maximum value for robots to be feasible. Results and implications will be discussed in chapter 7.

CHAPTER 2

THE OVERVIEW OF MUSHROOM INDUSTRY

1. Mushroom Cultivation Techniques

Out of 1.5 million estimated fungi, it was calculated that only about 140,000 species produce fruiting bodies of sufficient size and suitable structure to be considered as macrofungi (Hawksworth, 2001). According to the definition given by Chang and Miles (1992) "a macrofungus with a distinctive fruiting body which can be either epigeous (above ground) or hypogenous (under ground) and large enough to be seen with the naked eye and to be picked by hand can be called a mushroom."

Out of 140,000 species, only about 2,000 species are proven to be edible, but because of their specific aroma, flavor, and texture most of these edible mushroom species are of little consumer demand. Only about 50 species are cultivated on a commercial basis worldwide and about 300 species of so called "wild mushrooms" are reported to be widely consumed (Hawksworth, 2001).

There is one specie in the world, where cultivation and consumption exceeds the consumption of all other species combined. This specie is the agaricus bisporus, also called white button mushroom, or champignon. Its cultivation dates back to the early 1700's, when it was introduced by an unknown French horticulturist. In 1893, a cultivation method by inoculating and culturing the mushroom spawn after a medium sterilization process was invented in France. This was a turning point in the history of mushroom cultivation which made the mass-production of the agaricus mushrooms possible. Cultivation of agaricus spread rapidly after World War II when reliable spawn became commonly available in a number of countries (mainly the U.S., Netherlands, UK, and France). Within the last five decades agaricus bisporus cultivation in the world reached its present position as the zenith of the mushroom industry. The dominants of agaricus bisporus results from a solid foundation of scientific research in all aspects of agaricus biology and cultivation technology, along with the use of modern management principles. This foundation has also made possible a highly technical approach involving the creation and utilization of specialized equipment and advanced engineering technology. For instance, since 1965, the average yield per square foot for agaricus bisporus increased over 300%.

The agaricus mushroom cultivation systems can roughly be divided into two categories: the one zone system and the two zone system. The one zone system is a cultivation process where the compost making forming and fermentation procedures are done outdoors, and pasteurization and conditionings, hyphal incubation, and the mushrooms culturing are done indoors in the same culture room. In the two zone system, the pasteurization, conditionings, and occasionally the hyphal incubation procedures are practiced in facilities like a tunnel or a special pasteurization room, and the mushrooms culturing elsewhere. Where mushroom cultivation is practiced by small scale farmers, the former method is generally preferred, and the latter is used with an automated, specialized mass-production system, from compost making to harvest of the products is established.

The materials for the compost of agaricus mushrooms are cereal straw (wheat straw, rice straw, and barley straw), animal manure, corn cobs, cotton seed hulls, cocoa seed hulls, gypsum, and nitrogen supplements. The ingredients are mixed considering the content of nitrogen and carbon they contain, and go through outside fermentation and reversing processes. In places where environmental factors are automatically regulated, the outside fermentation is done in facilities similar to a bunker where air is ventilated through its floor. Because of the environmental problems due to the offensive smell and the waste water, the number of mushroom farms where this process is done in a closed environment is increasing. Manufacturing the compost in a place where environmental factors can be controlled, the compost is produced free from limitations that change in environmental surroundings. It takes approximately three weeks to prepare the medium.

The prepared compost goes through the pasteurization and conditionings processes in a tunnel, a special pasteurization room, or in a culture room where the one zone system is practiced. The pasteurization process kills harmful insects and nematodes, bacterium, and some fungi that the compost contains, and aids in the growth of the useful microbes. It is also changes ammonia, which can be harmful for mycellium, making the compost suitable for hyphal growth. The pasteurization and conditionings processes take approximately one week. When the compost is cooled after the conditioning process, the compost is inoculated with the mushroom spawn and is put into trays, vinyl bags, shelves, or other tunnels for hyphal incubation.

In the one zone system, the process takes place in the same bed. According to different species and environments, the hyphal incubation period lasts about 14 days. When the process is over, the casing soil is placed on the compost. In the two zone system, the medium after the hyphal incubation is put in trays, vinyl bags, or in shelves, and then the casing soil is applied on top. In order to obtain a constant rough structure and moisture prevention capacity, which are the characteristics for good casing soil, each producing firm follows its own recipe of slightly different materials and blending ratio. Generally firms produce their casing soil with peat, sugarcane bagasse, cocoa fiber, and limestone mixed together with other materials. After seven to nine days when mycellium appears on 60 to 70% of the casing soil layer, the germinating process is promoted through ventilation, lowering of temperature, and supply of water, and after 10 to 15 days of such a process, mushrooms are ready for picking.

The entire life span of a carpophore is up to three weeks, but it takes, under normal conditions, only a week to ten days for the primordium to grow to the point when the mushroom should be picked. This is just before the vail breaks, and the steams are still whitish, so that by the time they reach the customer the surfaces are still white, the veil not more than partly broken, and the steam not deeper colored than a light pink.

If the mushroom is picked too young, the sorting process will add it to the specimens of inferior quality because of its small size. If not picked premature, it could have been graded with a higher priced size, by allowing it to remain on the beds for an extra day or two. Also, the mushroom was, at the time of picking, in the process of actively adding weight. The loss in yields if mushrooms are consistently picked too early can be considerable. If, on the other hand, the mushroom is picked when it's too old, i.e. after the veil breaking , it will reach the customer in a stage of flabby, spongy consistency, and darkened all over. There is also hardly any weight gain in leaving specimens on the beds after the breakage of the veil. Apart from appearance, the culinary value of a fully mature mushroom is not equal to that attained before full maturity.

Regardless which zonal system is used all the processes described above are mechanized in all modern U.S. production processes except for harvesting. A list of mechanization is:

- Straw breaking and pre-wetting machines
- Overhead filling systems
- Compost hoppers
- Blending lines
- Tray filling and emptying lines

- Tray transport systems
- Tunnel filling cassettes
- Tunnel emptying winches
- Spawning lines
- Head filling machines
- Casing machines
- Pulling winches for shelf systems
- Bag filling machines
- Blocking machines
- Irrigation units in growing rooms
- Air handling units and climate control systems
- Automated mushroom harvesters for canning industry
- Mushroom slicers and packing equipment

The only stage of mushroom cultivation that is virtually not mechanized yet is mushroom picking for fresh market.

Mushroom Lifecycle

Regardless of the species, several steps are universal of all mushrooms. The role of the producer is to isolate a particular mushroom species from the highly competitive natural world implant it in an environment that provides the mushroom a distinct advantage over competing organisms. The three phases in their lifecycle are:

1. Spore collection, spore germination and isolation of mycelium.

2. Preparation of inoculum by expansion of mycelial mass on enriched agar media and then on grain. Implantation of grain spawns into composted and uncomposted substrates or the use of grain as a fruiting substrate.
3. Fruit body (mushroom) initiation and development. Mushrooms are the fruit of the mushroom plant, the mycelium. A mycelium is a vast network of interconnected cells that permeates the ground and lives perennially.

This resident mycelium only produces mushrooms under optimum conditions of temperature, humidity, and nutrition. For the most part, the parent mycelium has but one resource for insuring the survival of the species: to release enormous number of spores. Those spores in turn are producing a primary mycelium. When the mycelium originating from two spores mates, a secondary mycelium is produced. This mycelium continues to grow vegetatively. When vegetative mycelium has matured, its cells are capable of a phenomenal rate of reproduction which culminates in the erection of mushroom fruit body. This represents the last funetical change and it has become in effect, tertiary mycelium. These three types of mycelia represent the three major phases in the progression of the mushroom lifecycle (Stamets, 1983).

The control of mushroom cropping has many aspects. One having considerable commercial potential is distributing the overall yield of sporophores more or less evenly over several successive flushes (Stamets,1983). The usual pattern of mushroom cropping is to harvest the first or second flush the heaviest with later flushes becoming progressively smaller until further cropping becomes uneconomic. Heavy flashes put considerable strain on the labor resources of a mushroom producer. The presence of many sporophores growing close together often leads to excessive stipe growth caused by the carbon dioxide trapped beneath the massed pilei. Moreover, the sporophore caps become misshapen during expansion and quality suffers.

The relative yield in successive flushes can be influenced to some extent by the spawn strain used. Some spawns will tend to produce a heavy first or second flush, others may tend to be more evenly sized. However, trends are not consistent. They are modified by the particular conditions under which the crop is grown. Choice of spawn strain has, therefore, only limited value in controlling relative flush size.

The idea of controlling the production of mushrooms to fit a pre-determined program is not new. Hauser and Sinden demonstrated a considerable degree of control over alternative cultural and environmental factors. They adjusted the timing of such processes as spawning and casing, and by strict control over environmental factors they were able to ensure maximum production of mushrooms in the middle of the week and to arrange for a minimum of harvesting being required during national holidays (Hauser and Sinden, 1959).

Production of Fresh and Processed Agaricus Mushroom in U.S.

Based on a report released August 15, 2003, by the National Agricultural Statistics Service production and sales reported by producers of agaricus mushrooms for fresh market in August, 2002- July, 2003 are 692 million pounds, virtually unchanged from the previous year. At the same time sales of agaricus mushrooms for processing are 139 million pounds a 2% decline from the previous year.

As indicated in Table 2.1, the fresh market for mushrooms dominates over processed and the freshmarket has a tendency for future expansion. In the early 1990s processed mushroom sales were more than 30% of total mushroom sales; by 2003 the market share of processed mushrooms was only 17% and declined of over 40%. One explanation of this decline is that during the last decades processed mushroom imports increased significantly, and substituted domestic production.

Table 2.1. Agaricus Mushrooms: Sales by Type and Percent of Total, United States, 1990-2003

Year	Fresh Market		Processing		Total
	Volume of Sales (1000 pounds)	Percent	Volume of Sales (1000 pounds)	Percent	Volume of Sales (1000 pounds)
1990	511,904	72	203,088	28	714,992
1991	511,921	68	237,230	32	749,151
1992	496,959	67	249,873	33	746,832
1993	522,381	67	253,976	33	776,357
1994	516,836	69	233,963	31	750,799
1995	532,232	68	250,108	32	782,340
1996	537,124	69	240,746	31	777,870
1997	553,780	71	222,897	29	776,677
1998	621,537	77	187,141	23	808,678
1999	657,833	78	189,927	22	847,760
2000	668,541	78	185,853	22	854,394
2001	692,630	82	153,579	18	846,209
2002	689,968	83	141,139	17	831,107
2003	692,451	83	138,863	17	831, 31

Source: National Agricultural Statistics Service, August 15, 2003

Price and Value of Fresh and Processed Mushrooms in the U.S.

Prices for mushrooms described in Table 2.2, are the average price producers receive at the point of the first sale, commonly referred to as the average price as sold.

Table 2.2. Agaricus Mushrooms, Price and Value by Type of Sale

	Fresh Market		Processing		All Sales	
Year	Price per pound	Value of Sales	Price per pound	Value of Sales	Price per pound	Value of Sales
1990	1.000	512,055	0.653	132,683	0.902	644,738
1991	0.981	501,967	0.615	145,948	0.865	647,915
1992	0.995	494,340	0.638	159,501	0.875	653,841
1993	0.998	521,566	0.582	147,832	0.862	669,398
1994	1.030	532,863	0.662	154,810	0.916	687,673
1995	1.050	560,127	0.684	171,046	0.935	731,173
1996	1.090	588,126	0.579	139,452	0.935	727,578
1997	1.090	605,728	0.559	124,568	0.940	730,296
1998	1.080	670,168	0.553	103,449	0.957	773,617
1999	1.080	712,000	0.611	116,098	0.977	828,098
2000	1.070	715,943	0.606	112,608	0.970	828,551
2001	1.060	736,543	0.579	88,957	0.976	825,500
2002	1.150	796,522	0.525	74,051	1.050	870,573
2003	1.120	774,088	0.559	77,561	1.020	851,649

Source: National Agricultural Statistics Service, August 15, 2003

For example, if in a given state, part of the fresh mushrooms are sold F.O.B. packed by growers, part are sold bulk to brokers or repackers, and some are sold retail at roadside stands, the mushroom average price as sold is a weighted average of the average price for each method of sale.

As indicated from Table 2.2, during the last decade the price for fresh mushrooms increased approximately 12%, while the price for processed mushrooms declined from 65 cents per pound in 1990 to 56 cents per pound in 2003.

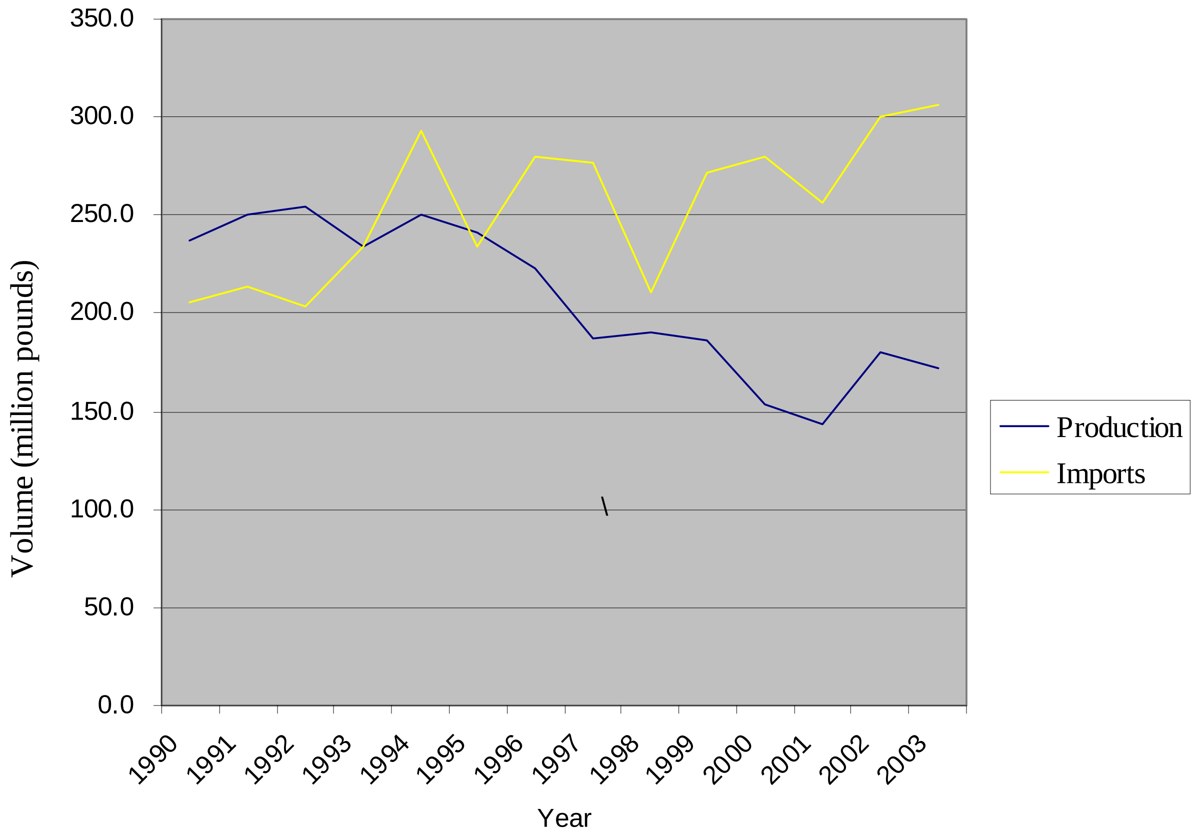

Figure 2.1. Production and Imports of Processed Mushrooms in the U.S., 1990-2003

Source: Economic Research Service, Mushroom Statistics, 5/20/03, web source <http://www.ers.usda.gov/catalog/OneProductAtATime.asp?ARC=c&PDT=1&PID=169>

A major reason for these price changes is the market for fresh mushrooms in U.S. are mostly controlled by large U.S. producers and they are able to determine the price level by taking into consideration their cost of production and demand for fresh mushrooms. In the case of processed mushrooms foreign competitors are determining prices for mushroom.

The condition of the price for processed mushrooms per pound being lower than for the fresh market also makes process mushrooms less attractive for U.S. producers. As indicated from Figure 2.1 during the last decade (1994-2004) imports of processed mushrooms increased approximately 50% and U.S. production declined over 40%.

Number of Growers, Areas of Production, Yield, and Dollar Volume per square foot.

Number of growers of agaricus mushrooms is declining through time. During the last three decades, the number of growers declined by over four times. A major cause for this decline is the profitability of production is highly dependant on the scale of operations. Currently large producers (which produce over 20 million pounds per year) account over 62% of total production of mushrooms. In Figure 2.3 a pie chart illustrates the breakdown of the producers in accordance with the volume of production. As pie chart indicates approximately 50% of producers produce in a range from one to five million pounds of fresh agaricus mushrooms per year, and there are only a few small farms, which produces annually less than 0.5 million pounds. The largest mushroom producing company in U.S. is Monterey Mushrooms. They currently produce over 40% of U.S. agaricus mushrooms (Summerfield, 2004). It is hard for small producers to compete with large ones, because most of highly technological machinery is designed for large scale of operations and not suitable for small scale producers. Being unable to organize efficient production process they have to quit (Summerfield, 2004).

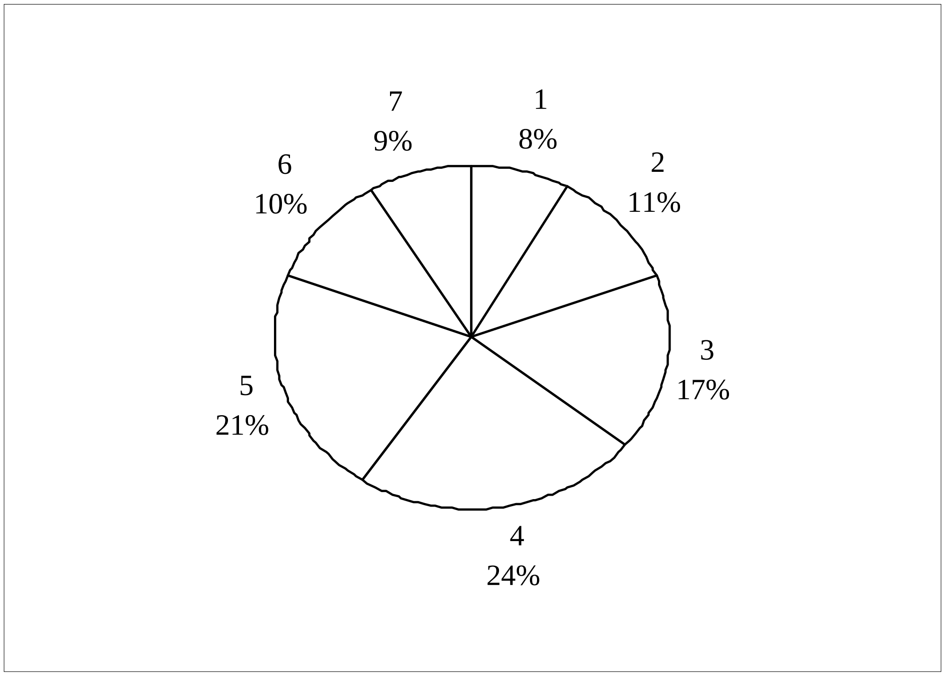

Figure 2.3. Percent of the producers in accordance with the volume of Production.

Key: 1. Over 20.0 million pounds

2. 10.0 million to19.9 million pounds

3. 5.0 million to 9.9 million pounds

4. 2.5 million to 4.9 million pounds

5. 1.0 million to 2.4 million pounds

6. 0.5 million to 1.0 million pounds

7. less than 0.5 million pounds of sales

Source: National Agricultural Statistics Service, August 15, 2003

As indicated from Table 2.3 during the last decade the number of growers declined by over 35%, with the area in production and yield per square feet increasing. This increase in dollar volume per square foot directly corresponds to mushroom profitability, given the relatively stable sales prices. The main problem facing that mushroom producers is how to cut expenses per square foot.

Table 2.3. Agaricus Mushrooms: Number of Growers, Area in Production, Yield, and Dollar Volume per Square Foot, United States, 1989-2003

Year	Growers	Area in Production	Yield per Square Foot	Dollar Volume per Square Foot
	Number	(1,000 Square Feet)	(Pounds)	(Dollars)
1990	259	137,861	5.19	4.68
1991	238	139,922	5.35	4.63
1992	226	138,148	5.41	4.73
1993	195	141,909	5.47	4.72
1994	193	135,703	5.53	5.07
1995	186	139,617	5.60	5.24
1996	180	135,320	5.75	5.38
1997	165	136,461	5.69	5.35
1998	156	145,094	5.57	5.33
1999	151	150,017	5.65	5.52
2000	147	151,487	5.64	5.47
2001	137	143,873	5.88	5.74
2002	128	140,822	5.90	6.18
2003	126	140,864	5.90	6.05

Source: National Agricultural Statistics Service, August 15, 2003

U.S. Specialty Mushrooms Production

All mushroom species other than agaricus sold in U.S. market are known as a specialty or medicinal mushrooms. As indicated in Table 2.4 all specialty mushrooms combined have less than 2% of the U.S. mushroom market. Specialty or medicinal mushrooms cannot be considered as a substitute for agaricus mushrooms, because of their specific taste and consistency.

Table 2.4. U.S. Specialty mushrooms production.

	Production			Volume of sales		
Crop year	Shiitake	Oyster	Other	Shiitake	Oyster	Other
	(1,000 pounds)			(1,000 pounds)		
1987	1,203	1,041	223	1,144	896	219
1988	1,517	574	375	1,353	544	328
1989	2,112	1,242	481	1,916	1,169	481
1990	2,430	1,402	558	2,209	1,315	533
1991	2,553	1,242	692	2,323	1,203	622
1992	2,802	1,098	776	2,537	1,046	684
1993	2,965	1,089	961	2,752	1,000	817
1994	5,732	2,062	993	5,559	1,939	906
1995	5,649	1,980	1,165	5,396	1,800	1,046
1996	6,140	1,941	1,495	5,665	1,791	1,379
1997	7,025	2,695	1,609	6,661	2,542	1,485
1998	6,624	2,210	1,277	6,281	2,073	1,168
1999	8,680	3,729	1,256	8,254	3,547	1,201
2000	8,635	3,573	1,326	8,173	3,346	1,211
2001	9,778	3,817	1,397	8,939	3,629	1,316
2002	8,263	4,265	1,541	7,893	4,028	1,424

Source: Economic Research Service, Mushroom Statistics, 5/20/03, web source http://www.ers.usda.gov/catalog/OneProductAtATime.asp?ARC=c&PDT=1&PID=169

As also indicated in Table 2.4 there is a difference between the produced and sold volume of specialty mushrooms. Those losses result from producers of specialty mushrooms producing on a small scale. It is hard to organize effective logistics, no steady demand, and marketing opportunities are not comparable with those that exist for the agaricus industry.

On the other hand, during the last two decades production volumes of specialty mushrooms has increased over seven times in response to the increase in demand. More restaurants are offering specialty mushrooms in their menus (Lavier, 2002).

Imports and Exports of Fresh and Processed Mushrooms in the U.S.

Taking into consideration that the post harvest life of the agaricus mushrooms varies from one to ten days, it is even theoretically impossible to imagine the logistics of fresh mushroom exports to U.S. from the Eurasian continent. Thus, it could be assumed that production of fresh mushrooms is taking place within state boundaries. The exemption is probably the neighboring countries in the European Union, where the absence of trade barriers enables low transportation costs.

During the last three decades canning made it possible to ship the mushroom to more distant parts where the fresh product would not survive intact. Canning has also made the eating of mushrooms a year round event since consumers were no longer limited to purchasing mushrooms during the cooler months of the year when growing was possible. The advent of mushroom canning and development of an extremely popular snowball strain of the agaricus mushroom helped make mushroom farming an international industry (Flammini, 1999).

As indicated in Figure 2.3, the volume of imported canned mushrooms was volatile over the last decade, but this volatility has a tendency to decrease, as the market for fresh mushrooms is strengthening its position on the local market.

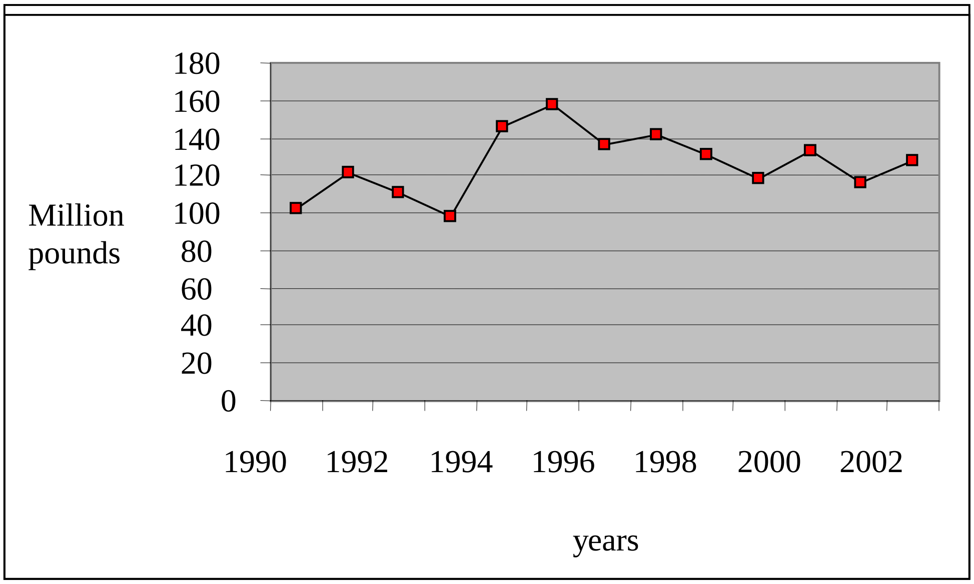

Figure 2.3. U.S. mushroom imports: All canned (preserved), 1990-2002

Source: Bureau of the Census, Department of the Commerce. Economic Research Service Data, Mushroom Statistics, 5/20/03, web source
http://www.ers.usda.gov/catalog/OneProductAtATime.asp?ARC=c&PDT=1&PID=169

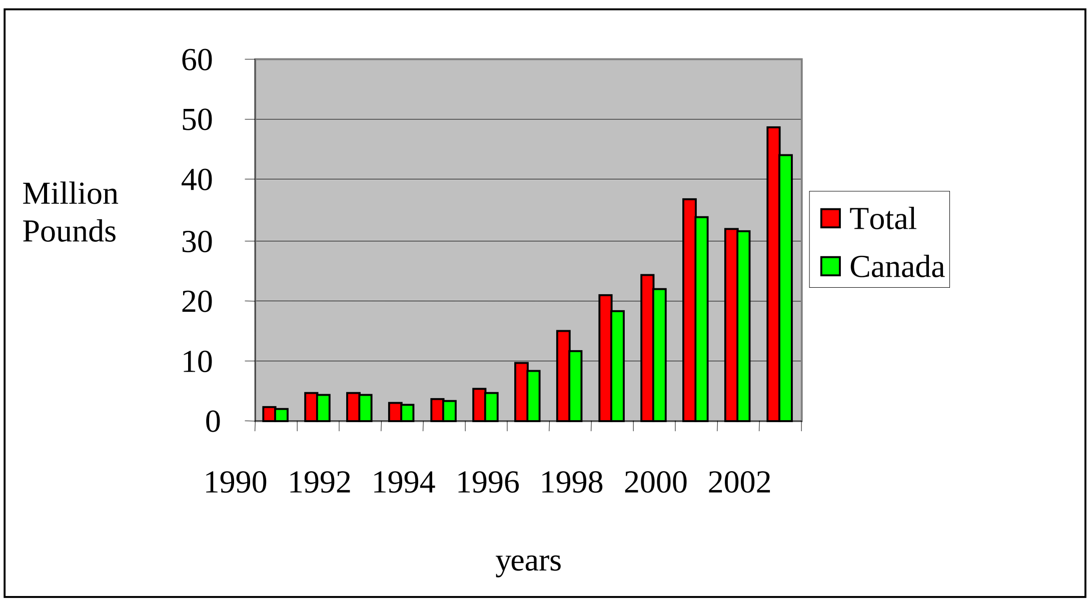

Figure 2.4. U.S. Mushroom Imports: Fresh market 1990-2002

Source: Bureau of the Census, Department of Commerce, Economic Research Service Data, Mushroom Statistics, 5/20/03, web source
http://www.ers.usda.gov/catalog/OneProductAtATime.asp?ARC=c&PDT=1&PID=169

As indicated in Figures 2.4 and 2.5, the U.S. fresh mushroom trade has very small volume compared to the processed (Figure 2.3.), and in case of the U.S is virtually limited to trade with Canada.

Due to similar productivity and level of technological development, but slightly lower cost of labor and favorable exchange rate, Canada is able to export to U.S. over eight times more mushrooms than it imports.

Another possible factor for this trading imbalance is due to fact that for some northern states, mushroom producers located in Canada are geographically closer, than those located in mushroom producing states. Thus, due to the advantages of the NAFTA agreement, Canadians have a comparative advantage in those U.S. states.

On the other hand, Canada has sufficient mushroom producers not to allow producers from Pennsylvania to have a similar advantage.

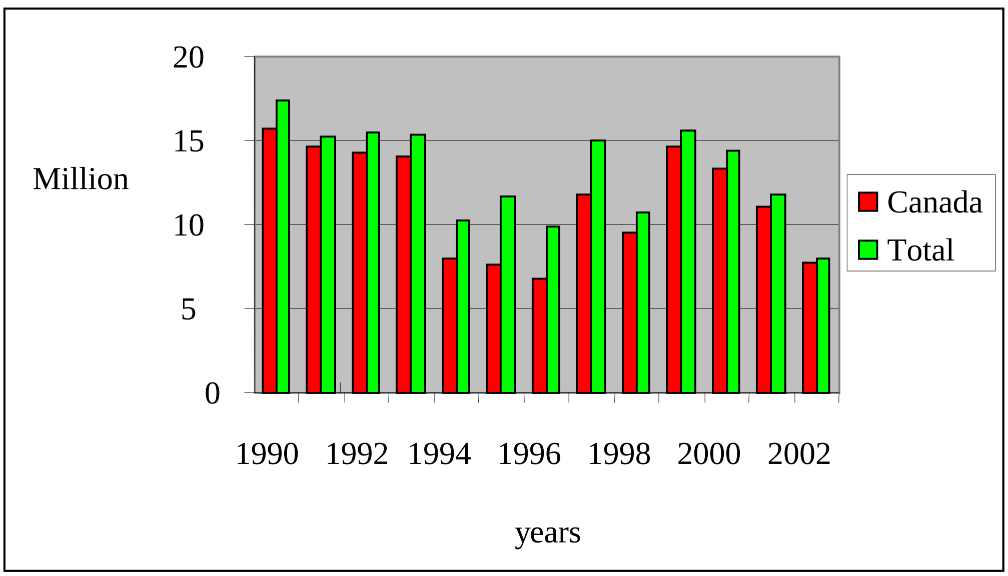

Figure 2.5 U.S. Mushroom Exports: Fresh market, 1990-2002

Source: Bureau of the Census, Department of Commerce and Statistics Canada, web source http://www.ers.usda.gov/catalog/OneProductAtATime.asp?ARC=c&PDT=1&PID=169

World's Largest Producers and International Trade

United States is the world's second largest agaricus mushroom producer behind China. The major reasons for the U.S.'s position are stable local markets for fresh mushrooms and the transportation difficulties of fresh mushrooms.

Table 2.5. World Canned Mushroom Import by Volume (pounds), 1990 to 2002

Year	Germany	United States of America	France	Japan	Russian Federation	Netherlands	Canada
1990	352,055	101,242	36,656	23,089	-	13,470	43,875
1991	377,681	121,308	40,868	33,774	-	17,720	48,510
1992	385,768	114,583	32,204	30,686	33	27,027	41,120
1993	334,732	98,706	23,410	37,013	546	25,436	38,481
1994	300,696	141,909	27,583	46,649	0	21,610	55,333
1995	281,999	161,313	42,515	54,478	0	34,660	38,411
1996	275,828	137,492	70,358	50,070	9104	43,524	28,572
1997	222,930	141,880	62,177	56,916	22097	39,451	20,481
1998	250,436	126,143	68,833	58,833	22672	45,519	14,200
1999	284,767	118,116	78,711	63,373	9,490	39,506	21,460
2000	266,474	150,434	79,008	64,204	21,956	43,105	43,789
2001	250,771	131,995	80,939	68,105	35,200	27,226	26,346
2002	237,348	128,049	77,106	70,851	37,816	29,886	29,225

Source: FAO,United Nations, Economic Research Service Data, Mushroom Statistics, 5/20/03, web source http://www.ers.usda.gov/catalog/OneProductAtATime.asp?ARC=c&PDT=1&PID=169

As indicated from Table 2.5. and 2.6. U.S. also the second largest importer of processed mushrooms behind Germany. Germany, U.S. and Japan are leading the list of processed mushroom importers due to high labor cost in these countries and labor intensive requirements in mushroom industry.

Table 2.6. World Canned Mushroom Import by Value (1,000 dollars), 1990 to 2002

Year	Germany	United States of America	Japan	France	Netherlands	Italy	United Kingdom
1990	314,362	127,746	20,921	37,489	13,275	13,290	16,957
1991	309,067	141,737	28,375	36,081	16,688	17,502	16,872
1992	318,149	129,731	28,442	29,494	20,037	22,546	17,047
1993	235,042	103,139	34,277	21,808	18,383	17,533	13,223
1994	228,770	151,537	44,400	29,994	18,436	25,663	17,934
1995	250,931	184,283	57,337	45,530	32,887	22,364	15,310
1996	221,504	133,985	58,531	58,040	36,414	26,417	16,024
1997	144,289	125,775	54,744	60,663	23,781	34,617	13,508
1998	164,017	113,006	53,395	50,878	27,477	21,717	15,232
1999	188,515	119,384	57,028	56,096	26,211	20,967	15,251
2000	142,094	146,328	55,452	50,621	24,803	16,843	12,770
2001	129,559	123,884	58,500	54,307	15,632	14,486	13,431
2002	123,744	100,061	65,211	50,237	20,131	17,609	14,523

Source: FAO,United Nations, Economic Research Service Data, Mushroom Statistics, 5/20/03, web shttp://www.ers.usda.gov/catalog/OneProductAtATime.asp?ARC=c&PDT=1&PID=169

During last decade the share of Chinese exports of processed mushrooms to U.S. decreased over 3 times (ERS data, 5/20/03). The major cause of this decline is that United States has tighten its regulations for Chinese firms after a scandal that happened ten years ago related to contaminated mushrooms shipped from China to the U.S. (Henkel, 1992).

Table 2.7. World Canned Mushroom Export by Volume (pounds), 1990-2002

Year	China	Netherlands	Spain	France	Indonesia	Poland	Germany
1990	286,187.2	317,351.76	40,804.86	111,357.1	13,984.38	0	6,078.63
1991	292,157.8	342,327.48	33,287.01	125,416.42	16,349.27	0	5,655.46
1992	295,849.53	316,659.7	28,039.29	150,766.82	40,535.97	19,670.7	6,845.62
1993	301,802.54	308,665.79	29,476.3	135,404.95	29,189.78	13,215.18	5,518.82
1994	350,017.24	403,296.73	48,549.71	122,480.69	38,060.88	12,366.64	6,083.04
1995	444,784.83	383,575.34	49,400.46	95,457.44	41,437.4	13,237.22	9,902.57
1996	402,712.68	402,849.31	51,688.2	110,427.01	46,812.96	17,259.52	7,991.7
1997	356,358.1	302,981.7	53,843.72	95,763.8	40,178.92	17,836.97	7,200.47
1998	356,748.3	185,129.4	56,459.87	101,860.1	17,486.54	22,685.77	23,214.73
1999	362,776.2	343,586	62,820.61	86,112.48	50,601.64	31,673.68	20,827.8
2000	508,835.3	223,778.7	82,892.44	81,162.3	57,929.94	41,631.36	17,651.84
2001	491,500.8	283,568.8	78,429.34	74,415.86	50,002.15	42,199.99	18,667.88
2002	488,043.2	279,986.7	81,002.4	71,672.7	50,502.45	44,022.87	18,600.2

Source: FAO, United Nations, Economic Research Service Data, Mushroom Statistics, 5/20/03, web http://www.ers.usda.gov/catalog/OneProductAtATime.asp?ARC=c&PDT=1&PID=169

As indicated in tables 2.7. and 2.8. there are two large exporters for processed mushrooms in the world – Netherlands and China. But during last 5 years China was able to increase its export volumes significantly, while Netherlands faced some decrease compared with mid 1990s. The only advantage China has over other major producers is cheap labor, and given the mushroom industry is extremely labor intensive, China was able to increase its exports of processed mushroom to foreign countries from 50,000 MT to 250,000 MT during last 20 years.

Table 2.8. World Canned Mushroom Export by Value (1,000 dollars), 1990 to 2002

	China	Netherlands	Spain	France	Poland	Indonesia	Italy
1990	192,992	277,714	36,945	110,184	0	12,367	8,326
1991	180,990	269,394	31,331	117,707	0	16,997	9,959
1992	170,225	253,636	26,083	132,081	14,508	39,034	9,161
1993	150,990	231,594	23,203	92,111	9,390	20,556	11,516
1994	183,865	287,223	32,853	94,285	10,768	32,754	14,610
1995	273,748	303,268	39,713	93,506	17,157	38,570	17,091
1996	210,920	289,224	39,593	96,169	21,646	36,370	17,430
1997	169,052	191,407	36,691	80,277	15,273	23,505	28,555
1998	163,137	115,052	40,207	68,294	17,738	10,348	14,124
1999	162,995	227,722	46,729	63,128	25,195	27,910	15,000
2000	204,385	167,265	51,333	53,547	28,349	31,287	11,111
2001	196,227	149,277	50,308	47,363	32,287	25,824	13,112
2002	190,021	146,877	54,877	44,600	37,002	28,993	12,989

Source: FAO, United Nations, Economic Research Service Data, Mushroom Statistics, 5/20/03, web http://www.ers.usda.gov/catalog/OneProductAtATime.asp?ARC=c&PDT=1&PID=169

As indicated in Table 2.7, China currently has the dominant position today in processed mushroom exports. Taking into consideration that in China the average mushroom picker receives $2-3 per day, China has an absolute advantage in mushroom production. For the U.S. producers to remain competitive they must reduce their costs. A robot may aid in these cost reduction.

CHAPTER 3

MANUAL AND AUTOMATED MUSHROOM HARVESTING SYSTEMS

The Main Characteristics of Manual Mushroom Harvesting in the U.S

Mushroom picking was always considered one of the most unattractive jobs in the U.S. In accordance with the journalist from *Philadelphia Enquirer,* S. Flammini "The (mushroom) industry as a whole, and Kaolin Mushroom farms in particular have been the focal point of a labor movement seeking better conditions for the often abused predominantly migrant workforce utilized to harvest and pack the crop. Since the birth of mushroom farms in Chester County, PA (first mushroom farms where founded there), the harvesting of mushrooms has been the job of those on the lowest rung of our nation's socioeconomic hierarchy for the mere fact that no one else is willing to do it. Since 1975, when the Federal government has allowed farm workers to unionize, mushroom pickers have used every opportunity to protest against bad working conditions and low wages." (Flammini, 1999).

During the last decade the biggest boycotts took place in 1997 at the Quincy Farms, Tallahassee, Fl, in 1999 in Kaolin Mushrooms, Kennett Square, PA, and in 2002 in Pictsweet Mushrooms, CA (Peter Oei, 2003).

There are many articles from 1995- to present, describing safety rules violations by mushroom producer's management, complains of violation of state low minimum wages, for enforced and unpaid overtime, and for terrible working conditions. The following statement is extracted from one of the typical articles, "The workers at Quincy Farms first invited the union to help them organize because of the bad working conditions they endure. Mushrooms are harvested on elevated beds, which are slippery because they are wet. Workers frequently fall and twist their ankles, or get injured because of the working conditions.

To do the harvesting, workers must climb up beds ten feet high, carrying baskets that can weigh up to 30 pounds. The most common workplace accident occurs among the pickers who fall from the beds while harvesting, and hurt themselves. After they fall, the company then has them sign a statement where the worker takes full responsibility for the accident" (Gainsville Iguana, 1997).

Ninety percent of mushroom pickers in U.S. are Hispanic, the majority of which are immigrants (Peter Oei, 2003). Picking mushrooms is not a desired occupation for domestic labor.

Agaricus mushroom cultivation has its technological requirements and while implementing them it creates the following difficulties for the workers:

1) Mushroom growing rooms require low lighting. As a consequence pickers are working in the semi darkness, which hurts their eye vision over long time periods.

2) Air moisture content of growing rooms should be maintained on a 95% level. Consequently, working eight or more hours in such a humid environment can cause serious health problems over time.

3) The mushroom trays are stuck sometimes ten feet high (the top is fifteen feet high). Mushroom pickers must then climb up to ten feet high for harvesting. A falling can cause serious injury and possibly fatalities.

4) During heavy first and second flushes labor is forced to work overtime, because otherwise it will not be possible to harvest in time all the fruits. There is an option that management could employ additional part-time labor during flushes, but the cost of hiring and training exceeds the benefits.

5) Because trays are placed on different levels (about 30 inches apart on top of each other), the mushroom pickers have to pick as low as 25 inches from the surface of the floor, and sometimes balance in the air in between the trays to pick from the top trays. As a consequence, most of the mushroom pickers complain from suffering back pain and other related muscular conditions.

These are the major undesirable working conditions that are directly derived from production requirements. However, there are other conditions related with discriminatory and unfair management. This makes manual mushroom picking undesirable work, especially relative to its wage rate.

The Evolution of Automated Harvesting Systems

The idea to use mechanization to reduce picking cost in the mushroom industry is as old as commercial mushroom cultivation itself. In the U.S. one of the first developments allowing to increase productivity of pickers and reduce average picking cost per pound of mushrooms was the development in the late 1960s of a harvesting system involving picking lines, parlors or stations (Hopper 1971). In this system, mushroom trays are taken, usually by fork-lift truck, from the cropping houses to a central picking area where the trays passed along a moving bench on each side of which are teams of pickers. The trays are watered at the end of the line before being re-stacked and returned to the growing rooms. The benefits of this system included easier and more rapid harvesting, better working conditions for the pickers, opportunity to moisturize compost evenly, and greater ease in spotting disease outbreaks. Furthermore, it was possible to fit additional trays into growing rooms, because no space was needed for picking. Several farms invested in these sets of machinery, but within a short period of time it became clear that there were many problems arising during operating this system (Flegg 1985). One of the most difficult faced by the pioneers of picking lines was how to ensure that all the mushrooms were ready for harvest on all trays at the same time. It is often found necessary to pass all the trays through the line when only a small proportion had mushrooms ready to pick. Frequent stacking and restacking of the trays on the picking lines was a labor intensive process, so the overall process was economically not feasible.

The next step is development of a mechanical harvesting system (Persson, 1972; Vedder, 1978). Improved versions of those machines are widely used today in European mushroom canneries. For this to be really successful, with minimum loss of quality and reduction of marketable yield, all the mushrooms on a bed should be ready to harvest at the same time, be uniformly spaced and be growing from a level surface. If they are not, the knife blades of the harvester moving over the beds will cut into the caps of immature sporophores as well as stripes of older ones and sometimes cut into the undulating surface casing layer. Uniformity of environmental conditions, ruffling the casing layer, and ensuring a level bed surface can each facilitate the use of mechanical picking machines. The speed of mechanical harvester exceeds many times the speed of labor, but because of the reasons described above it is not suitable for fresh market. The latest developments assigned to substitute manual labor in mushroom picking are automated harvesting robots described below.

The Robotic Automated Harvesting System

Cultivation techniques are not the only factors influencing fresh mushroom quality. The harvesting method also seriously affects the final quality. Mushrooms lack an epidermis and are therefore a highly sensitive product. For example, the shelf life of mushrooms is halved if they are subjected to a short and mild mechanical damage treatment of shaking the mushrooms in a polystyrene box for 10 seconds (Burton & Noble, 1993).

The lack of dents and bruises will increase the post harvest life of the mushrooms and consequently the final sales price will depend on product appearance.

The robotic system developed by Silsoe Research institute entails a series of consecutive tasks involving identifying a suitable target in terms of size and location, picking the mushroom in a manner that does not damage or contaminate it or its neighbors, trimming the stipe, and carefully placing it into a container. The robotic harvesting program was therefore divided into a set of related tasks covering mushroom location, sizing, selection, picking, grading, trimming and transfer. The overall plan for the research was to develop automatic methods for carrying out each of these tasks and to incorporate and combine the ideas on a laboratory rig.

During their trials monochrome video camera was employed by a pilot harvester for viewing the mushrooms. The camera was mounted approximately one meter above the mushroom casing layer (Reed, 2001).

The basic location algorithm relies on the fact that when lit and viewed from above, a mushroom surface acts as a Lambertian reflector, with the domed top of the mushroom appearing brighter than the sides. A scan of the image to detect all pixels with relatively high grey levels separates the brighter spots representing the reflective tops of each mushroom. By calculating the areas of these spots, a first estimate of the mushrooms centre positions can be determined. From each of these start points the algorithm then searches radially outwards looking for pixels at a lower, common grey level depicting the edge of the mushroom.

The picking strategy or selection algorithm assesses the bearing and range of all adjacent mushrooms with respect to each other. The objective of the program is to determine whether enough space is available to allow any given mushroom to be bent in one of the eight radial directions. If a direction is blocked, the program reports as to whether the mushrooms are overlapping, touching, or not touching but too close to permit bending. Using this technique results in two mushroom lists: those ready for picking and those that are blocked. Further selection criteria may be applied at this stage, such as picking mushrooms only above a certain diameter. The resulting data is then passed to the robot controller, and picking commences. After each mushroom has been picked the selection strategy routine re-analyses the scene to reveal any newly available mushrooms as they become unblocked. If a geometric arrangement of mushrooms occurs in which all mushrooms are mutually exclusive, the largest mushroom in the group is picked by twist alone to provide the picking space for the others. If the suction cup fails to make proper contact, or an available mushroom fails to be picked for any reason, the system can optionally return the suction cup to the mushroom for a second attempt. If this should also fail, the mushroom is abandoned but knowledge of its position and size is retained for the program to check whether it poses a barrier to picking other mushrooms. Development of the selection strategy and picking hardware was expedited by using imitation mushrooms, made of dental plaster, when real mushrooms were not available.

One of a pair of suction cup mechanisms attached to the single head of a Cartesian robot is then deployed; it can delicately detach individual mushrooms and place them gently into a specially designed, compliant finger conveyer. After high speed trimming a gripper mechanism is finally used to remove mushrooms from the conveyor into packs at the side of the machine. In accordance with author, the quality levels attained are as good or better than achieved by hand picking (Reed, 2001).

In comparison of both systems, automated harvesting robots are definitely a step forward compared to manual picking. They almost totally eliminate all negativity that makes manual harvesting an undesirable job, and allow producers to cut their variable cost by about 15 to 20%. However, for the economic feasibility of the robots compared with labor should be determined.

One major advantage of manual picking over automated, is the efficiency of labor compared to robots. The productivity of labor is twice as faster as of robots. Also, the procurement and installation of robots requires significant initial capital investments, and with manual labor, management has more flexibility (there is no need for picking lines with manual labor harvesting system).

CHAPTER 4

THEORETICAL FRAMEWORK

When a technological innovation is introduced, not everyone adopts it at the same moment. Rather, there will be innovators and there will also be laggards. Based upon the examination of a large number of studies in innovation diffusion, Rogers proposed a method of adopter categorization. Rogers suggested that the normal curve be described as follows:

- the first 2.5% of the adopters are the "innovators"
- the next 13.5% of the adopters are the "early adopters"
- the next 34% of the adopters are the "early majority"
- the next 34% of the adopters are the "late majority"
- the last 16% of the adopters are the "laggards"

For a technological innovation to take off, the first two groups are the most important ones (Rogers, 1995).

It is hypothesized by adopting mushroom harvesters, innovators and early adopters can earn a positive net return by decreasing their cost of production. The shaded area in the Figure 4.1., labeled as “Adopting Firm” represents this positive net return. However, as more firms adopt the harvester, the market supply curve shifts to the right, from Q^S to $Q^{S'}$. The equilibrium price will then fall, eventually eliminating any net returns (Wetzstein, 2004).

As indicated from the shaded area in the Figure 4.1. labeled “Nonadopting Firm”, the firms which do not adopt the harvester will operate at a loss in the short run and will have to shut down in the long run.

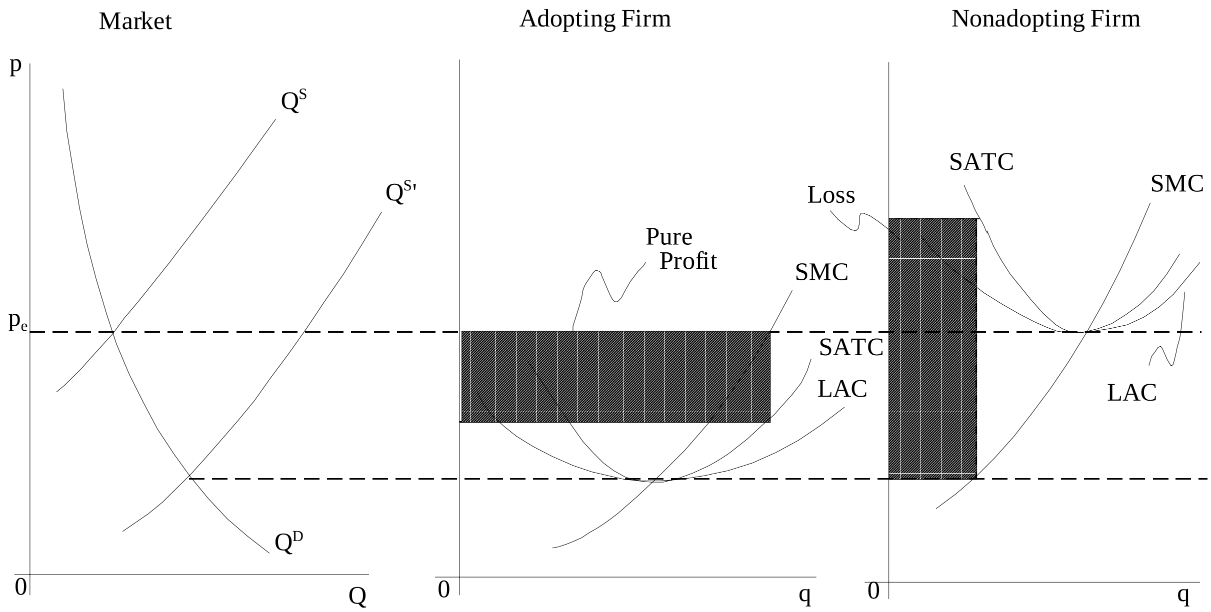

Figure 4.1. Introduction of a new technology

Prior to making a decision concerning the adoption of a new technology, innovators should calculate all the cost and benefits associated with harvester adoption. One of the widely used approaches in the investment decisions is the present value analysis, which takes into consideration the stream of benefits and costs through time.

Present value analysis is employed in investment decisions for describing the process of determining the worth in today's dollars of cash flow to be received in the future. The present value of a future cash flow represents the amount of money today, which, if invested at a particular interest rate, will grow to the amount of the future cash flow. The process of finding present values is called discounting and the interest rate used to calculate present values is called the discount rate.

For example when a firm buys a harvester, it is in effect buying a stream of net revenue in future periods. In order to decide whether to purchase this harvester, the firm should compute the present discounted value of this stream. Only by doing so will the firm have taken adequate account of the effects of foregone interest.

Consider a firm in the process of deciding whether to buy an automated mushroom harvesting robot. The harvester is expected to last *n* years and will provide a stream of monetary returns in each of the *n* years. Let the gross return in year *i* be represented by R_i. If *r* is the discount rate, and if this rate is expected to prevail for the next *n* years, the discounted present value (PV) of the revenue flow from the harvester is

(4.1) $PV = R_1/(1+r) + R_2/(1+r)^2 + \cdots + R_n/(1+r)^n$

This discounted present value represents the total value of the stream of payments that is provided by the harvester. If the PV of this stream of payments exceeds the initial cost (TFC) of the harvester, the firm, should consider adopting the harvester. Even when the effects of interest payments that the firm could have earned on its funds had it not purchased the machine are taken into account, the machine promises to return more than its initial cost. In contrast, if TFC > PV, the firm may be better off investing its funds in some alternative that promises a rate of return of *r*. When account is taken of foregone interest, the machine does not pay for itself. Thus, in a competitive market the only equilibrium that can prevail is that in which the cost of a machine is equal to the present discounted value of the net revenues from the harvester. Only in this situation there will be neither an excess demand for harvester nor an excess supply.

Generally, investment costs also vary, and may consist of the initial fixed cost, TFC, to acquire a harvester and then some variable costs incurred during each time period over the lifetime of the harvester. Let $STVC_i$ denote the level of variable cost in time period i. For example, in terms of the cost of owning an automated mushroom harvesting system, there is the initial purchased cost TFC then, the SVTC of electricity, maintenance and labor in each time period over the life of the machine. Subtracting STVC incurred in each time period from the benefits derived results in the net benefits per time period. Discounting these future net benefits to their present values and subtracting TFC yields the net present value (NPV),

$$NPV = -TFC + (TR_2 - STVC_2)/(1 + r) + (TR_3 - STVC_3)/(1 + r)^2 + \ldots + (TR_T + STVC_T)/(1 + r)^{T-1} + SV/(1 + r)^T,$$

where it is assumed the flow of net benefits starts in the second time period and SV represents the salvage value of the harvester. SV is value of a capital item at the end of the production process. In our particular case we assume that there is no salvage value for Cartesian robots.

Assuming this flow of future net benefits is known with certainty, then the investment with the highest NPV may be undertaken first. Further, assuming the investment options are independent, all options with NPV > 0 should be purchased (Wetzstein, 2004).

A special case of evaluating the present value of an asset is when the returns are constant through time, and salvage value is zero. Specifically, assume constant returns of (R-STVC) per period, then the discounted net present value is,

$$(4.2.)\quad NPV = -TFC + (R - STVC_2)/(1 + r) + (R - STVC_3)/(1 + r)^2 + \ldots + (R + STVC_T)/(1 + r)^{T-1}$$

where the returns start in the second period.

The assumption of returns being constant is based on mushroom prices exhibiting a stationarity process through time. Given monthly mushroom wholesale prices over a decade, an econometric test can be employed to reject the null hypothesis of a non stationarity price process.

A stationary process has the property that the mean, variance, and autocorrelation structure do not change over time. In contrast, most economic time series are not stationary. However, many of these series may be approximated by stationary processes if they are differenced. If a series must be differenced *d* times to make it stationary, it is said to be integrated of order *d.*

Numerous studies in econometrics deal with the question whether economic and financial data are best characterized by a deterministic trend or a stochastic trend (unit root) model (Maddala and Kim, 1998). Dickey and Fuller (1979) proposed a test which has become a standard for testing unit root against the alternative of stationarity. However, in small samples the unit root tests have a low power against the relevant alternatives such as long memory fractionally integrated errors (Diebold and Rudebusch, 1991) or stable autoregressive model with roots near unity. The low power may lead to the acceptance of the unit root hypothesis of the Nelson–Plosser series, when other approaches, developed by Perron (1989) and DeJong and Whiteman (1991) found very few of the Nelson–Plosser series to have unit roots. However, given relatively large sample (91 observations) for mushroom price series, the Dickey-Fuller test will be the best option for us to test price series for stationarity.

If the test will reveal, that price series are stationary, it will mean that mushroom price and associated sales revenues also will be constant through time. In this case reduction in the cost of production will increase profitability. These profits will be equal to the difference between cost of labor saved by adopting the new technology and maintenance cost of the robots. Of course the discounted present value of robots also should be taken into consideration.

In our opinion the Net Present Value, calculated by the formula represented in equation 4.2. is the best indicator to measure the level of economic feasibility for adopting automated mushroom harvesting systems. In our NPV calculation we will use sensitivity analysis approach and will discuss different values of such variables as cost of the robots, wage rates for labor, schedules for operating robots, and discount rates.

CHAPTER 5

TREND CONSTRUCTION AND TEST FOR STATIONARITY

Given monthly nominal wholesale prices for agaricus mushrooms for June 1995 – December, 2002, monthly agricultural price indexes for the same period of time was used to calculate real prices (ERS data, 5/20/03). Table 5.1. indicates basic statistical characteristics.

Table 5.1. Summary statistics on the U.S. mushroom monthly prices, U.S. $ per pound

Price Series	Mean	Variance	Minimum	Maximum
Nominal	1.30	0.004	1.25	1.42
Real	1.28	0.013	1.06	1.52

Source: Economic Research Service Data, Mushroom Statistics, 5/20/03, web source <http://www.ers.usda.gov/catalog/OneProductAtATime.asp?ARC=c&PDT=1&PID=169>

As indicated from Table 5.1., the variance of real price series is over three times higher than for nominal time series. Also, given the difference between minimal and maximal prices values for nominal and real series is $0.17 and $0.46 respectively, nominal time series has a smoother trend, than the real price series shown in Figure 5.1. below.

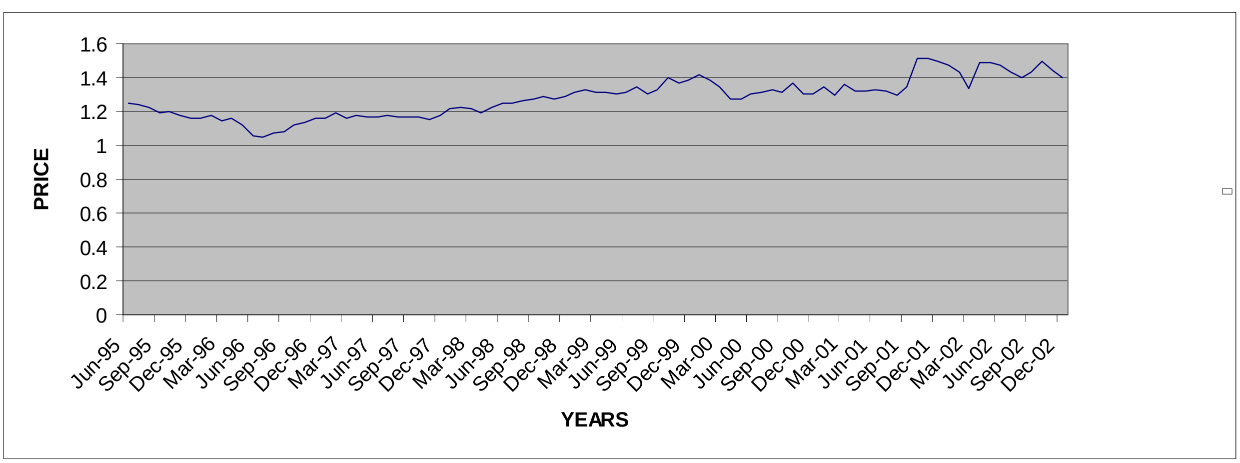

Figure 5.1. U.S. agaricus mushroom wholesale monthly prices, June 1995 – December, 2002

Source: Economic Research Service Data, Mushroom Statistics, 5/20/03, web source <http://www.ers.usda.gov/catalog/OneProductAtATime.asp?ARC=c&PDT=1&PID=169>

As indicated from Figure 5.1 mushroom prices have a tendency to increase. As a test for this possible trend null hypothesis on the existence of a unit root is specified. The rejection of this null hypothesis will indicate the presence of a stationary price series. This will then support employing equation (4.2) for determining the economic feasibility of a mushroom harvester.

The aim of the Dickey–Fuller test to determine whether a time series is stationary or, specifically, whether the null hypotesis of a unit root (which is nonstationarity) can be rejected. The rejection/acceptance decision of the null hypothesis of a unit root is based on comparing the obtained values of the respective test statistics with the tabulated critical values for a chosen significance level.

A time series can be nonstationary because of a deterministic trend (a stationary trend or TS series) or a stochastic trend (a difference stationary or DS series) or both. Unit root tests are intended to detect stochastic trend, although they are not powerful at doing so, and they can give misleading inferences if a deterministic trend is present but is not allowed for. The augmented Dickey-Fuller test, which adds lagged dependent variables to the test equation, is often used. Adding the lagged variables (usually at the rate corresponding to $n/3$, where n is the sample size) removes distortions to the level of statistical significance but lowers the power of the test to detect a unit root when one is present.

With the use of the Time Series Processor (TSP) econometric software, the Dickey-Fuller test was conducted based on 91 observations. This resulted in the following statistics.

P value = 0.02765

Dickey-Fuller statistic = - 4.639.

These statistics indicate the null hypothesis may be rejected at the predetermined 5% significance level. Thus, based on this test, the mushroom price series represents a stationarity process. The negative value of the Dickey-Fuller statistic is another argument in support of stationarity. This is because the critical values of the Dickey-Fuller tests are shifted to the negative part of real line. For example, the critical value for the Dickey-Fuller test at a sample size equal to 100 and the significance level of 5% is -1.57. For mushroom prices it is - 4.639. This implies the null hypothesis should be rejected.

Given that wholesale mushroom prices are stationary, equation 4.2. can be employed for the economic evaluation of the mushroom harvester.

CHAPTER 6

FEASIBILITY ANALISIS OF AN AUTOMATED HARVESTING SYSTEM

Based on the theoretical discussion in Chapter 4, the economic feasibility of using robotic system in a mushroom harvesting process is based on the approach that all positive net present values could be acceptable for the potential investors. From 4.2., the net present value (NPV) are calculated. Different scenarios for labor hourly wage, work schedule for robots, and discount rate are developed for investigating the sensitivity of mushroom harvester adoption. This sensitivity analysis is based on a comparison with manual labor for mushroom harvesting.

Tax incentives for investments are also considered by calculating the net cost of robots as the difference between its initial cost and the tax savings. Straight line depreciation for seven years with the 34% tax bracket was used to calculate tax savings. Six different scenarios were used for the cost of automated mushroom harvesting systems and NPV was calculated as the difference between PV and net costs.

Knowledge that the main operational part of automated mushroom harvesting system is so called pick and place Cartesian robots, technical characteristics for the robot were obtained from three different U.S. based manufacturers (Toshiba, Epson, and Techno-Isdel).

Given Cartesian robots are a relatively new innovation and there is no long history for analysis of their technical performance, limited data exists on the lifespan of these robots. All three manufacturers suggest a lifespan of ten years is a reasonable estimate, and currently there are producers which are using robots without serious problems (Marty Arnold, 2004).

Based on the specifics of robot operations, calculations were made regarding the variable cost of operation, which includes cost of utilities associated with machine operation and labor costs necessary for robot management. As table 6.1. indicates the total hourly variable cost for operating Cartesian robots is estimated at $1.17 (this amount may vary depending on the scale of operations, density, and size of mushrooms). This variable operating cost includes electricity cost, which is 0.5 kwt per hour or approximately 2 cents (Anna Dobbins, Toshiba, 2004) , and estimated $1.15/hour for labor cost based on the estimate that a forklift operator will be able to provide and restack back trays for 20 robots each hour and will receive $9.00 per hour. Also it was calculated that one operator will be assigned to each ten robots and will receive $7.00/hour. Calculations regarding labor requirements are based on the productivity of labor involved in similar operations in the existing farms (Summerfield, 2004). After dividing hourly wage by the number of robots assigned to each employee the cost for each robot per hour of operation was determined.

Table 6.1. Variable cost per hour for operating an automated harvesting machine

Description	Cost per robot
Wage rate for trays stacker	$0.45
Wage for robot operator	$0.70
Utilities	$0.02
Total	$1.17

Source: Dobbins Anna, Personal Communication, Provided information regarding hourly consumption of electricity by Cartesian robots.

For a comparison of manual versus automated harvesting systems, the crucial differences between these systems are listed in table 6.2.

Table 6.2. Comparison of Manual and Automated Harvesting Systems

Characteristics	Harvesting Systems: Manual	Harvesting Systems: Automated
Mushrooms harvested (per minute)[a]	18	9
Initial cost[b]	Zero	$45,000
Cost of Infrastructure[c]	Zero	$35,000
Variable Cost (per hour)[d]	$7.00	$1.17
Estimated Lifetime (hours)	-	40,000 to 48,000 hours
Other Characteristics[e]	Manual harvesting requires safety regulations and health issues	75% reduction in manual labor for harvesting

[a] Reed, J.N."An automatic system for harvesting mushrooms." *The Mushroom Journal*, 617(2001):15-23

[b] As a base expense average cost of Cartesian robots was calculated based on information provided by (1) Marty Arnold, Personal Communication, Epson Robots, February 12, 2004, (2) Anna Dobbins, Personal Communication, Toshiba, March 03, 2004

[c] Lange, E., Personal Communication, Christeans Group, Miami, FL, March 15, 2004.

[d] Azor, Moshe, Personal Communications, Provided information regarding average wage rates in U.S. for mushroom pickers, Miami, FL, 16 March, 2004. Sources for automated harvesting variable costs calculation are defined in table 6.1.

[e] Reed, J.N."An automatic system for harvesting mushrooms." *The Mushroom Journal*, 617(2001):15-23

Given the stationary nature of mushroom prices, total revenue R for each time period was calculated as the difference between labor wages and maintenance cost for operating robots. The difference in manual and automated harvesting systems productivity was taken into consideration. Specifically, manual labor picking speed is twice as fast as robot picking, so manual labor cost is divided by two and only then are hourly maintenance cost for robots deducted.

As an example, given a wage level of $7.00/hour and a 5% discount rate, PV for a robot which operates 80 hours a week is,

$$STVC_1 = STVC_2 = \ldots = STVC_N = (7.00/2 - 1.17)*80 \text{ hours}*52 \text{ weeks} = \$\ 9{,}693$$

Then, PV = 9,693/1.05 + 9,693/1.05^2 + . . . + 9,693/1.05^{10} = $74,845

For different levels of hourly wage and discount rates similar calculations are shown in Tables 6.3 and 6.4.

Table 6.3. Scenario 1: Present Value of cost savings with robots versus manual harvesting weeks/year, 80 hours/week

Hourly Wage	Discount rate		
	5%	8%	10%
$6.50	$66,814	$58,060	$53,167
$7.00	$74,845	$65,039	$59,558
$7.50	$82,875	$72,017	$65,948
$8.00	$90,906	$78,996	$72,338
$8.50	$98,937	$85,974	$78,729
$9.00	$106,967	$92,953	$85,119

Table 6.4. Scenario 2: Present Value of cost savings with robots versus manual harvesting weeks/year, 80 hours/week

Hourly Wage	Discount Rate		
	5%	8%	10%
$6.50	$83,518	$72,576	$66,459
$7.00	$93,556	$81,299	$74,447
$7.50	$103,594	$90,022	$82,435
$8.00	$113,633	$98,745	$90,423
$8.50	$123,671	$107,468	$98,411
$9.00	$133,709	$116,191	$106,399

The robot operating scenarios were developed based on the assumption that robots operate 80 hours per week and 100 hours per week (two shifts 8 hours each for 5 or 7 days a week). Assumptions were based on the adaptation to the working schedules in the existing farms where manual labor is used.

For calculating the NPV, the present values of the cost savings listed in Tables 6.3 and 6.4 should be compared with the TFC of a harvester. As indicated in Table 6.2 these fixed costs in the form of initial cost plus cost of the infrastructure can be substantial. However, the current federal tax code allows such costs as deductions from income. Assuming straight-line depreciation over seven years and a 34% taxable level of income, the present value of TFC may be calculated. TFC will vary by producer depending how well a harvester meshes with the current operation. Thus, alternative levels of TFC from $50,000 to $100,000 are investigated by taking into account the federal tax code and then deducting the resulting present value of TFC from the present value of cost savings in Tables 6.3 and 6.4. The resulting NPV's are listed in Tables 6.5 through 6.16.

Table 6.5. Scenario 1: NPV for a robot operating 80 hours/week, TFC = $50,000

	Discount rate		
Hourly Wage	5 %	8 %	10 %
$6.50	$30,867	$20,705	$14,991
$7.00	$38,898	$27,684	$21,381
$7.50	$46,928	$34,662	$27,771
$8.00	$54,959	$41,640	$34,162
$8.50	$62,990	$48,619	$40,552
$9.00	$71,020	$55,597	$46,942

Table 6.6. Scenario 2: NPV for a robot operating 100 hours/week, TFC = $50,000

Hourly Wage	Discount Rate		
	5 %	8 %	10 %
$6.50	$47,571	$35,220	$28,283
$7.00	$57,609	$43,943	$36,271
$7.50	$67,647	$52,666	$44,259
$8.00	$77,686	$61,390	$52,246
$8.50	$87,724	$70,113	$60,234
$9.00	$97,762	$78,836	$68,222

Table 6.7. Scenario 3: NPV for a robot operating 80 hours/week, TFC = $60,000

Hourly Wage	Discount rate		
	5 %	8 %	10 %
$6.50	$23,678	$13,234	$7,356
$7.00	$31,707	$20,212	$13,746
$7.50	$39,737	$27,191	$20,136
$8.00	$47,767	$34,169	$26,527
$8.50	$55,796	$41,148	$32,917
$9.00	$63,826	$48,126	$39,307

Table 6.8. Scenario 4: NPV for a robot operating 100 hours/week, TFC = $60,000

	Discount Rate		
Hourly Wage	5 %	8 %	10 %
$6.50	$40,381	$27,749	$20,648
$7.00	$50,419	$36,472	$28,636
$7.50	$60,456	$45,195	$36,623
$8.00	$70,493	$53,918	$44,611
$8.50	$80,530	$62,642	$52,599
$9.00	$90,568	$71,365	$60,587

Table 6.9. Scenario 5: NPV for a robot operating 80 hours/week, TFC = $70,000

	Discount Rate		
Hourly Wage	5 %	8 %	10 %
$6.50	$16,488	$5,763	-$280
$7.00	$24,518	$12,741	$6,111
$7.50	$32,548	$19,720	$12,501
$8.00	$40,577	$26,698	$18,891
$8.50	$48,607	$33,677	$25,282
$9.00	$56,636	$40,655	$31,672

Table 6.10. Scenario 6: NPV for a robot operating 100 hours/week, TFC = $70,000

	Discount Rate		
Hourly Wage	5 %	8 %	10 %
$6.50	$33,192	$20,278	$13,012
$7.00	$43,229	$29,001	$21,000
$7.50	$53,266	$37,724	$28,988
$8.00	$63,304	$46,447	$36,976
$8.50	$73,341	$55,170	$44,964
$9.00	$83,378	$63,893	$52,952

Table 6.11. Scenario 7: NPV for a robot operating 80 hours/week, TFC = $80,000

	Discount Rate		
Hourly Wage	5 %	8 %	10 %
$6.50	$9,299	-$1,709	-$7,915
$7.00	$17,328	$5,270	-$1,525
$7.50	$25,358	$12,248	$4,866
$8.00	$33,388	$19,227	$11,256
$8.50	$41,417	$26,205	$17,646
$9.00	$49,447	$33,184	$24,037

Table 6.12. Scenario 8: NPV for a robot operating 100 hours/week, TFC- $80,000

	Discount Rate		
Hourly Wage	5 %	8 %	10 %
$6.50	$26,002	$12,807	$5,377
$7.00	$36,040	$21,530	$13,365
$7.50	$46,077	$30,253	$21,353
$8.00	$56,114	$38,976	$29,341
$8.50	$66,151	$47,699	$37,329
$9.00	$76,189	$56,422	$45,317

Table 6.13. Scenario 9: NPV for a robot operating 80 hours/week, TFC = $90,000

	Discount Rate		
Hourly Wage	5 %	8 %	10 %
$6.50	$2,109	-$9,180	-$15,551
$7.00	$10,139	-$2,201	-$9,160
$7.50	$18,169	$4,777	-$2,770
$8.00	$26,198	$11,756	$3,620
$8.50	$34,228	$18,734	$10,011
$9.00	$42,257	$25,713	$16,401

Table 6.14. Scenario 10: NPV for a robot operating 100 hours/week, TFC = $90,000

	Discount Rate		
Hourly Wage	5 %	8 %	10 %
$6.50	$18,813	$5,336	-$2,259
$7.00	$28,850	$14,059	$5,729
$7.50	$38,888	$22,782	$13,717
$8.00	$48,925	$31,505	$21,705
$8.50	$58,962	$40,228	$29,693
$9.00	$68,999	$48,951	$37,681

Table 6.15. Scenario 11: NPV for a robot operating 80 hours/week, TFC = $100,000

	Discount Rate		
Hourly Wage	5 %	8 %	10 %
$6.50	-$5,080	-$16,651	-$23,186
$7.00	$2,949	-$9,672	-$16,795
$7.50	$10,979	-$2,694	-$10,405
$8.00	$19,009	$4,285	-$4,015
$8.50	$27,038	$11,263	$2,376
$9.00	$35,068	$18,241	$8,766

Table 6.16. Scenario 12: NPV for a robot operating 100 hours/week, TFC = $100,000

	Discount Rate		
Hourly Wage	5 %	8 %	10 %
$6.50	$11,624	-$2,136	-$9,894
$7.00	$21,661	$6,587	-$1,906
$7.50	$31,698	$15,311	$6,082
$8.00	$41,735	$24,034	$14,070
$8.50	$51,773	$32,757	$22,058
$9.00	$61,810	$41,480	$30,046

As indicated from in these tables only in 20 cases out of 216 the Net Present Value is negative. It indicates that in 93 % of the cases generated in our sensitivity analysis adoption of automated mushroom harvesting system is economically feasible. As the tables also indicate as the discount rate or cost of the robots increase the NPV declines, while increases in the wage rate and hours operated are increase NPV.

Results also reveal that if robots are operating 100 hours a week, then for the robots with a cost of $80,000 or lower, adoption is feasible regardless the level of wages or discount rates.

With the only exception in Table 6.15. we can see that it is feasible to use robots, when wage rate is $8.00 and higher regardless of the discount rate.

Probably the most crucial variable affecting the Net Present Value is the discount rate. As the tables indicate, given a 5 % discount rate only in Scenario 11 producers may face losses if they adopt the new technology.

Producers facing relativity high wage rates and the ability to adopt a harvester at a low level of TFC will be the early adopters. If their aversion to risk is also low, represented by a low discount rate, then as indicated in Tables 6.5 through 6.10, their NPV can exceed the TFC for investing. This represents a hurtle rate exceeding one (hurtle rate = NPV/TFC). Generally, firms require a hurtle rate of two or three before they will consider an investment. The uncertainty, irreversibility, and ability to delay the investment decision of acquiring a machine harvester accounts for this hurtle rate. A rule of thumb is to undertake an investment only if it results in $1 back each year for every $2 spent initially. Although for some scenarios the hurtle rate is approaching two, generally the rate is much lower. Thus, unless conditions change the adoption of machine harvesters will probably be limited in the near future.

CHAPTER 7

CONCLUSIONS

An economic feasibility analysis of adopting robotic mushroom harvesters in the U.S. industry was undertaken in this study. One of the major goals was to analyze the advantages and disadvantages of using robots in mushroom harvesting.

To analyze the economic feasibility of automated harvesting systems adoption (1) mushroom monthly wholesale price series for stationarity was tested using the Dickey-Fuller test. Results reveal that the price series is stationary. Specifically the series has a constant mean, variance and covariance, which in turn supports the assumption that mushroom price and associated revenues from fresh mushroom sales will not change over time.

Using different scenarios with various levels of hourly wage rate, discount rates, schedules for robot operations, and initial cost of robots over 200 Net Present Values were generated for automated mushroom harvesting systems. In 196 cases out of 216, the calculated Net Present Value was positive which supports the assumption that automated mushroom harvesting system is economically feasible (Reed, 2001).

Knowing that the estimated cost for automated harvesting robots and its appropriate infrastructure is approximately $80,000, from Tables 6.11. and 6.12., if the labor wage is $7.50 or higher, it may feasible to adopt the new technology regardless of the discount rate.

Mushroom producers located in areas, where due to higher cost of living, hourly wage rates are higher for example California, may be the early adopters compared with those states where the minimum wage requirements are lower.

Based on the analysis conducted in Chapter 6, a robotic system is economically feasible if operated 100 hours a week and price is not exceeding its estimated value. Given that the minimum wage rate in California is $6.75/hour (Dept. of Labor, 2004), the producers can expect net returns from 10% to 40% depending on the discount rate applied. However, the hurtle rates for all the alternative scenarios below that generally required for adoption. This probably accounts why no producers are currently using automated harvesting systems. Until there is some structural shifts in costs or technology in harvesters specifically and mushroom production in general, producers will probably not be adopting harvesters soon.

Besides the numerical analysis discussed in Chapter 6, there are other advantages of automated mushroom harvesting systems, that are difficult to measure, but are very important to consider while estimating overall feasibility of adopting the new technology.

Except for unit productivity and some flexibility (with manual labor there is no need to re-stack trays) there are no non-cost advantages of using manual harvesting instead of robots. On the other hand, there are many problems with the use of existing manual harvesting systems, and employment of robotic systems allows eliminating or at least reducing those negative issues. In general those improvements are described as follows:

- Robotic systems will allow improved working conditions for the remaining pickers and will eliminate most of the safety issues existing today (e.g.high stacked trays and heavy buckets).
- Taking into consideration that robots could work up to 24 hours a day, it will provide more flexibility to organize harvest during heavy first flushes, and will eliminate or significantly reduce the need for producers employing labor overtime.
- The quality of mushrooms harvested with the help of robots is higher than harvested manually in terms of damages occurred during harvest.

- The use of picking lines optimizes the exploitation of growing facilities, because it will be possible to stack trays higher and denser. This in turn will reduce electricity costs and increase production volume.

The following is a list of factors that increase the feasibility of robotic harvesting systems:

- Development of new mushroom strains, able to provide faster colonization of compost and even density of fruitbodies during flushes, will enable reduced requirements for manual labor in the beginning of the harvesting process.
- Use of casing materials with higher density and proper technological characteristics, the improvement of current pinning techniques, and the increasing yields per square feet of growing area, will enable using the robots more efficiently through the picking lines and the fungi lifecycle. This will in turn decrease the required labor cost associated with stacking and restacking of the trays.
- Innovation of different compost additives and nutritional supplements will allow adjusting agaricus lifecycle to the required production technology. For example, it is possible to decrease several times, the time necessary for primordium to convert into fruitbody ready to harvest. It in turn will enable the use of robots almost permanently for up to 24 hours a day, which is fully possible for Cartesian robots of the current generation.
- As was earlier discussed in Chapter 3 expected legislative changes will indirectly force mushroom producers to increase wages for mushroom pickers and will directly force some farms to invest substantial amounts of money to improve working conditions and safety of manual pickers. In this situation use of robots is a possible solution to avoid future “legislative pressure.”

- Taking into consideration significant per capita agaricus mushroom consumption rate increased during the last decade and population growth in general, there are definite opportunities for future expansion and development of the U.S. mushroom industry. Lower cost of mushroom production will enable producers to decrease the price and increase profitability due to increased production volumes.

Will these additional advantages lead to an acceptable hurtle rate? It depends on the unique production systems and local environmental conditions a particular producer is facing.

REFERENCES

Arnold, M. Personal communication, Provided price and estimated lifetime of the Cartesian robots manufactured by Epson, email, February 12, 2004

Azor, Moshe, Personal communication, Provided information regarding average wage rates in U.S. for mushroom pickers, Miami, Fl, 16 March, 2004.

Burton, K S; Noble R. "The influence of flush number, bruising and storage temperature on mushroom quality." *Post harvest Biology and Technology*, 3(1997):39-47.

Chang, J. and Miles P.A. "Mushroom biology: a new discipline." *The mycologist* 6(1992):64-65.

DeJong, D. N. and Whiteman, C. H. "Reconsidering trends and random walks in macroeconomic time series." *Journal of Monetary Economics* 28(1991):221–254.

Dickey, D. A. and Fuller, W. A. "Distribution of the estimators for autoregressive time series with a unit root." *Journal of the American Statistical Association* 74(1979)427–431.

Diebold, F. X. and Rudebusch, G. D. "On the power of Dickey–Fuller tests against fractional alternatives." *Economics Letters*, 35(1991):155–160.

Dobbins, A., Personal communication, Provided information about lifetime and price of Cartesian robots manufactured by Toshiba, March 03, 2004

Economic Research Service Data, Mushroom Statistics, 5/20/03, Washington DC, web source (http://www.ers.usda.gov/catalog/OneProductAtATime.asp?ARC=c&PDT=1&PID=169)

Farrar J. *Economics of mushroom production crop year 1997. Farm business Unit CAFRE School of economic studies*, The University of Manchester, Manchester, UK, 1997.

Flegg P. B., Spenser D. M., Wood D. A. *The biology and technology of the cultivated mushroom.* Oxford, Oxford Press, 1985.

Lange, E. Personal communication, Provided information regarding estimated cost of tray lines suitable for automated mushroom harvesting, Miami, Fl, March 15, 2004.

Lucier G.,Allshouse J., and Lin Biing-Hwan, **“**Factors Affecting U.S. Mushroom Consumption”, Outlook Report No. (VGS295-01), March, 2003, web source (http://www.ers.usda.gov/publications/VGS/mar03/vgs29501/)

Hauser, E., and Sinden, J. W. “Mixed Spawning.” *MGA Bulletin*, 110 (1959):39-40.

Hawksworth, D.L. “Mushrooms: The extend of the unexplored potential*.”* *International Journal of Medicine mushroom* 3:(2001): 333-337.

Henkel, J. U.S. Food and Drug Administration, Investigators report, web source (http://www.fda.gov/fdac/departs/596_irs.html)

Hopper J. “ The Hopper system points the future.” , *Journal of Agricultural Engineering Research* 68(1971):14-17.

Maddala, G. S. and Kim, I.-M. *Unit Roots, Cointegration and Structural Changes*. Cambridge University Press. 1998, pp.95-103.

National Agricultural Statistics Service. “Mushrooms”, Report released on August 15, 2003

Nelson, C. R. and Plosser, C. “Trends and random walks in macro-economic time series: some evidence and implications.” *Journal of Monetary Economics*, 10(1982):139–162.

Noble R; Burton K.S. “Postharvest storage and handling of mushrooms: physiology and technology.” *Postharvest News and Information*, 4(1993):125-129.

Noble, R. Rama, T. “Influence of compost and casing layer depths on the mechanical properties of mushrooms.” *Annals of applied biology* 131(1997):079-090.

Perron, P. “ The great crash, the oil price shock, and the unit root hypothesis.” *Econometrica* 57(1989):1361–1401.

Rogers, E. *Diffusion of Innovations.* New York, NY, The Free Press, 1995, pp.17-31.

Raymond, S. "Recent developments and Future Possibilities in the Agaricus spp (Button mushroom) industry." Paper published in World mushroom society journal, 2003, web source http://www.mushworld.com/sub_en.html

Reed, J.N. "An automatic system for harvesting mushrooms." *The Mushroom Journal* 617(2001):15-16.

Reed J.N., Miles S. J., Butler J., Baldwin M., Noble R. "Automatic mushroom harvester development." *Journal of Agricultural Engineering Research*, 28/1(1997): 15-23.

Reed J.N.; Crook S. "Harvesting mushrooms by robot." *Proceedings of the 14th International Congress on the Science and Cultivation of Edible Fungi*, Oxford, 1995, Vol. 1, pp. 85-391

Reed J.N.; Tillett R.D. "Initial experiments in robotic mushroom harvesting." *Mechatronics* 4(1998):65-279

Stamets, Paul, *The mushroom cultivator : a practical guide to growing mushrooms at home* Agarikon Press, Seattle, Wa, Homestead Book Co., 1983, pp. 103-106.

Summerfield, L. Personal communication, Miami, Fl, March 15, 2004

USDA, National Agricultural Statistics Service, *Mushrooms 1995 –2003*, Washington DC, 2003 web source http://jan.mannlib.cornell.edu/reports/nassr/other/zmu-bb/

USDA, Department of the Interior , Bureau of Land Management. "Mushroom picking: what makes a good harvest?", Washington DC, 2001.

U.S. Department of Labor, Employment Standards Administration Wage and Hour Division, Washington DC, web source http://www.dol.gov/esa/minwage/america.htm#California

Wetzstein, M.E. *Microeconomic Theory: Concepts and Connections*. Thomson South-Western Publisher, 2004.