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Forecast of development trends in Taiwan's machinery industry

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Abstract

Industry transformation oriented toward high technology is being expected in the next 10 years by targeting Taiwan becoming an island of the technology. The machinery industry, which has been playing a vital role in Taiwan's economic development in the past, should be continuously emphasized during the course of the future development. This paper presents a detailed study on the future development of Taiwan's machinery industry along with the valuable proposals to the government policy and the investment strategy to the private sectors. The 10-year forecasting survey based on the strength, weakness, opportunity and threats (SWOT) analysis was made through an integrated professional team using the Delphi method. The derived results of market growth forecasting and the projected high potential products are further elaborated in the paper.
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1. Introduction

Machinery industry is important in Taiwan's overall industry development. The statistics in 1997 indicated that there were about 11,500 machinery factories, accounting for 14.8% of the

Abbreviations: SWOT, strength, weakness, opportunity, treat; CD-ROM, compact disc read-only memory; NC, numerical control; CNC, computer numerical control; FMS, flexible manufacturing system; CIM, computer-integrated manufacturing; CV, coefficient of variation; 3C, computer, communications, consumer electronics.

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total manufacturing industry. There were more than 145,000 people employed in this industry. The production value of machinery industry was about US$14.4 billion, representing 6.1% of Taiwan's total production value. The machinery export was US$9.7 billion, or about 8% of total exports. The export of leather shoes manufacturing machinery was second in the world with 23.6% market share, while woodworking machinery was third with 15%, and machine tool was fifth with 6%. Meanwhile, molds and plastic machinery was in the 6th place [1] (see Table 1).

In recent years, Taiwan's machinery industry has been facing pressure from a number of serious problems such as the high rising land cost, high construction cost, labor shortage, high percentage of less competitive factories with small-scale production, long payback years and new competition from other developing countries. Asian economic turmoil in the past 2 years also hurt the market in the region.

The Taiwanese government has listed the precision machinery industry as one of the 10 most important targeting industries in the government resources allocation with higher priorities. Most of those related government industrial policy and business incentives do not involve long-term planning, only up to 3 or 5 years. This research aims to have a 10-year forecast for the machinery industry in which the business directions, the major products with their key components in most great potential markets and the major issues to be faced with possible resolutions are to be studied. Our purpose is to provide the government and private sectors the important references for their long-term planning in the policy making and business decisions up to year 2010.

Table 1
Hot list of the major industrial machinery exporting countries in 1997

	Rank							
	1st Place		2nd Place		3rd Place		Taiwan ranks	
Item	Country	%	Country	%	Country	%	Rank	%
Plastic/rubber machinery	Germany	22.2	Japan	18.1	Italy	12.4	6	5.9
Machine tool	Japan	30.4	Germany	19.4	Italy	9.7	5	6.0
Food processing machinery	Germany	22.3	Italy	21.0	USA	12.6	14	1.6
Leather shoes machinery	Italy	40.1	Taiwan	23.6	S. Korea	8.2	2	23.6
Paper/printing machinery	Germany	26.9	USA	15.1	Japan	11.4	12	2.0
Pneumatic/hydraulic	Germany	35.3	England	9.7	Italy	8.9	10	2.4
Chemical machinery	Germany	19.3	USA	16.0	Japan	15.6	8	3.4
Textile machinery	Germany	22.2	Japan	22.1	Italy	11.8	6	6.0
Wood machinery	Germany	22.8	Italy	22.1	Taiwan	14.7	3	14.7
Transport machinery	USA	21.3	Japan	18.4	Germany	13.3	20	0.1
Molds	Japan	23.2	Germany	13.2	USA	11.5	6	7.0
Elec. tool	USA	16.6	Germany	15.1	Japan	14.1	8	4.3
Pump, fan, compressor	USA	21.9	Germany	17.7	Japan	15.3	9	2.6
Bearing	Japan	25.0	Germany	17.6	USA	12.5	13	1.2

In total, the list includes the 15 EU countries, USA, Canada, Japan, Europe, S. Korea, and Taiwan, for a total of 21 major industrial countries.

Data source: Datastar/Gardner Publication (⟨www.gardner/web.com⟩) internet/EU, USA, Japan, R.O.C. customs' import/export database.

To forecast the future potential products and key technologies in Taiwan's machinery industry, this paper briefly describes the forecasting method and explains the reasons for using this method, known as the Delphi method. The machinery industry history and its development in Taiwan and some other major countries, especially in Japan, were also introduced as a general background. The study was done with a strength, weakness, opportunity and threat (SWOT) analysis, followed by a forecast using the Delphi method. Finally, the conclusions and suggestions are made by summarizing both the introduction and the results of the Delphi method. The structure of this study is illustrated in Fig. 1. This paper forecasts the future potential products of Taiwan's machinery industry in the year 2010. The forecasting is made based on the information provided by experts and by using the Delphi method. However, the secondary data used in the introduction is mainly from domestic and foreign articles, government publications, and CD-ROMs.

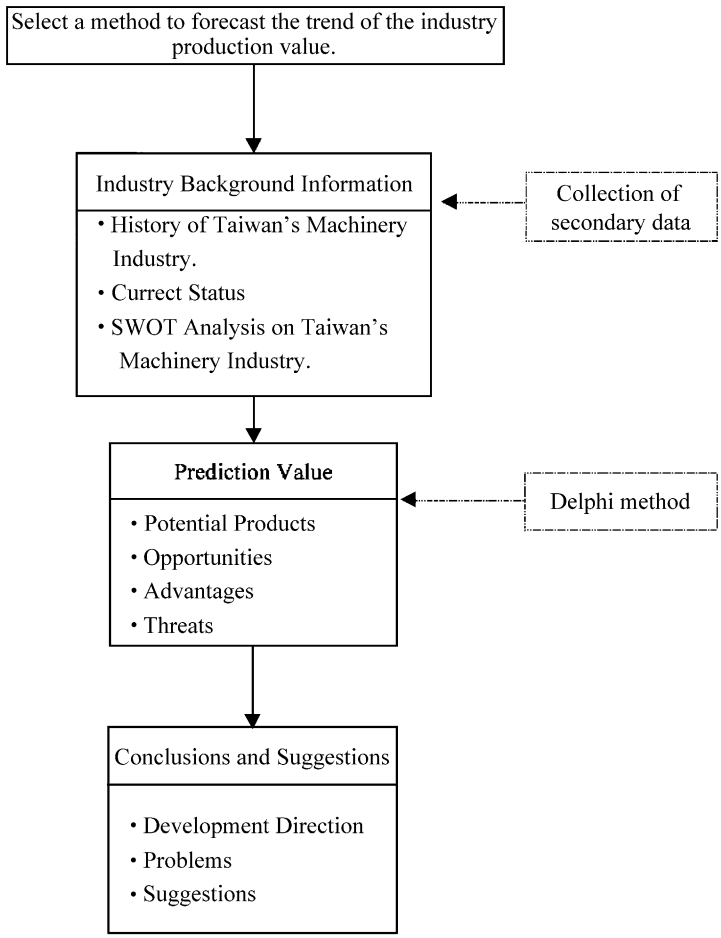

Fig. 1.

2. Delphi method

This research is a long-term industry forecast, and the Delphi method is the method used conventionally for achieving this [2–4].

The Delphi method was developed in the early 1950s by Rand, an American-based company. It is an expert forecasting method mainly used for long-term forecasting. The Delphi method helps us to find out the consensus among experts. This approach not only gathers various ideas, but also maintains expert independent judgement. It is a method of gathering ideas systematically and presenting a complete result after discussion.

The first step in applying the Delphi method is to form a team of experts. Then, every expert in the team has to answer a series of questionnaires. The answers will be analyzed and the results will serve as a guide in preparing a further questionnaire or alternatively an individual interview for each expert until a consensus of experts' opinion is acquired. A special negotiator is needed when using the Delphi method to negotiate, prepare questionnaires, and summarize the experts' forecast. Current expert forecasting methods typically have two shortcomings. The defect of the "individual forecasting method" is that it does not gather general ideas, while the defect of the "small team discussion method" is that is loses the independent judgement of individual experts. However, the Delphi method combines the two and has the advantages of both. There are three key concepts in the Delphi method:

1. The questionnaire is done anonymously to eliminate face to face psychological influences.
2. There is a repeated feeding process to amend initial ideas and to find extreme ideas.
3. The results are shown in terms of probability to eliminate the pressure of unique result trends.

We applied the Delphi method to forecast the future potential products in Taiwan's machinery industry in the year of 2010. The actual research method is as follows.

This research period is from September 1998 to April 1999.

(1) Designed questionnaire (see Appendix A).

(2) Formed an experts list and invited experts.

Since the experts must have adequate professional knowledge, experience and wisdom, this research used the following conditions as a guide for inviting experts: (a) must have at least 10 years of relevant experience, (b) must have bachelor's degree or above, (c) must have at least 3 years of experience as a supervisor or leader in a research project.

Following the above guidelines, 10 machinery industry experts were invited to form an expert team. This research group total included 10 experts, two research personnel, and two statistical analysis personnel.

(3) For the first round of questionnaires (from October 14, 1998 to November 15, 1998), the team members reviewed the subject and provided the experts with reference information such as yearly production value of the machinery industry, export value, and growth rate data. The experts then provided their opinions on the selected forecasting subject, doing so independently and without interference from each other.

(4) For the second round of questionnaires (from December 1, 1998 to December 31, 1998) the research personnel objectively summarized and tabulated the forecasting results from the first questionnaire. Based on these results, the experts were to give their second forecast and ideas.

(5) A third questionnaire was conducted (from January 16, 1999 to February 10, 1999), based on the different ideas from the second forecasting results. A conclusion was performed based on this questionnaire.

(6) Conclusion.

A conclusion was drawn based on the final forecast tables. Initial observation of the experts' ideas makes it obvious that they reflected the actual condition of the industry; moreover, every expert had the same opportunity to express his own ideas.

3. Development of the machinery industry

3.1. Scope of the machinery industry [5]

(1) Machine tool: lathe machines, drilling machines, cutting machines, rubbing machines, sawing machines, press machines, NC machine tool, unconventional machine tool, etc.

(2) Industry machinery: textile machines, leather shoes manufacturing machines, food processing machines, chemical industry machines, rubber and plastic machines, paper and printing machines, woodworking machines, transport machines, packaging machines, metal casting machines, semiconductor manufacturing equipment, thin-layer processing equipment, etc.

(3) Environmental protection machinery and energy facilities: trash treatment facilities (trash furnaces), air pollution prevention facilities, sewage treatment facilities, noise prevention facilities, new energy facilities, energy recycling facilities, residual energy restoration facilities, etc.

(4) Heavy machinery: construction machines, harbor utility machinery, mining utility machinery, forklift, turbo, etc.

(5) Machine parts: spindle, valves, gears, bearings, pneumatic and hydraulic parts, screws, pumps, molds, fasteners, etc.

3.2. The development history of Taiwan's machinery industry

There are six stages of economic development in Taiwan's history since the end of the Japanese regime [6]: (1) economic restoration in the 1940s; (2) development of household supplies industries in the 1950s; (3) expanding exports and light industries in the 1960s; (4) development of capital and skill-intensive industries in the 1970s; (5) advanced technology industry development in the 1980s; (6) reengineering of enterprise structures in the 1990s.

Taiwan machinery industry followed the above pattern and developed restlessly. Based on the classifications defined by the Taiwanese governmental planning council, the development

Table 2
Development steps of Taiwan's machinery industry

Period	Significant economic plans	Development background	Major products
1945–1952 (restoration, starting)	–	After the Japanese regime, machinery maintenance was the major issue after restoration.	Cables, lights, simple parts.
1953–1960 (beginning)	Economic plan 1 and 2 (1953–1960)	Turning from maintenance to parts manufacturing, the household industries increased the industry prosperity.	Rice machines, food machines and woodworking machines.
1961–1972 (growing)	Economic plan 3–5 (1961–1972)	The mechanical industry became the priority industry. The Metal Research Center was founded in 1963 and has been assisting factories since then.	Sewing machines, bicycles, weaving machine parts.
1974–1981 (adjustment oil crisis)	Economic plan 6 (4 years) (1973–1976)	The mechanical industry was energy efficient with significant added value. It was very suitable for development.	Sewing machines, machine tool, etc.
1982–1991 (soaring)	Economic plan (10 years) (1980–1989)	An active strategy of fostering the machinery industry.	Sewing machines, machine tool, woodworking machines, textile machines.
1992–current (independent R&D)	National construction 6-year plan (1991–1996); Asian manufacturing center plan (1995–current)	Precision mechanical research centers and promotion groups were founded to work on the Asian manufacturing center.	Precision machine tool, semiconductor equipment, high-tech pollution prevention machines, key parts, medical care equipment, etc.

Data source: Taiwan Association of Machinery Industry "50 Year History of the Machinery Industry".

stage was roughly divided into the periods of restoration, restarting, nurturing, adjustment, growth and self-independent R&D, as demonstrated in Table 2 [7].

3.3. Current status of the advanced countries and Taiwan

Invention of the numerical control (NC) machine in 1955 ushered the machinery industry into the era of numerical controls. The introduction of the computer numerical control (CNC) machine in 1965 moved the industry into the era of computer numerical control. In the meantime, programmed robots were manufactured. Flexible manufacturing system (FMS) gradually become popular in 1975, while in 1985 computer-integrated manufacturing (CIM) combined with factory automation to totally overhaul the machinery industry. This history shows that only those companies that make the transformation from their traditional machinery industry could survive in this rapidly changing market.

For example, Japan has actively implemented intelligence engineering since 1985. This intelligence engineering includes artificial intelligence, intelligent sensing systems, feedback-controlled walking robots, and three-dimensional testing systems [8]. The implementation of these technologies has offered an opportunity for the machinery industry to show its potential. Laser was introduced into the machinery industry at this time, integrating optics and machinery. The United States announced PC-based controlled machine tools in the 199s. This move indirectly enhanced the influence of PCs in the machinery industries. Taiwan is a global leader in PC manufacturing, and this breakthrough will expand its profits in the machinery industry.

At the 1997 Japan Machine Tool Exhibition, Japan demonstrated various machine tools with the characteristics of high speed, sophistication, low cost, versatility, cleanliness, energy efficiency, and networking capability. These characteristics represented a revolution in the machinery industry [9,10]. Taiwan is currently number five in the world as a machinery exporter [11]. However, to maintain this position requires paying attention to developments in the industry and reacting accordingly.

Products tend to become "light, thin, short, small" in order to save energy and protect the environment. This raises new accuracy and size requirements for parts and rework facilities. Technological changes in the 21st century are forecasted to be moving toward [12]:

1. Machining accuracy: from micrometer to nanometer.
2. Machining mechanism: from brittle mode to ductile mode.
3. Amount of material removal: from chips to atoms to atom and generally invoking another revolution in manufacturing technologies. As a result, the machinery industry should be able to evolve from nanoengineering to microengineering.

Taiwan's semiconductor industry has been ranked as number four in the same business globally in terms of its sales revenue. The machinery plays an important role in the production of semiconductor chips. How to integrate the features in optics, machinery, electronics, and chemistry to develop a self-support semiconductor machinery market in the future becomes a major issue in Taiwan's machinery industry. In the meantime, attention should also be made to those traditional machinery businesses to upgrade the product added value by strengthening their technological capabilities.

The machinery industry has demonstrated its capability in blending optics, and mechanical, electronic and chemical engineering as it approaches the 21st century. Thus, the industry is leaving its old-fashioned "black hand" image behind. The arrival of the precision machinery era is opening the way for the machinery industry to combine with high technologies. This in turn raises the possibility of further enhancing the competitiveness of Taiwan's industry on the global stage.

3.4. SWOT analysis of Taiwan's machinery industry

Taiwan's machinery industry enjoys the advantages of a high-quality manpower, ample capital, comprehensive cooperative industry network, flexible and efficient, qualified and committed graduates, good pool of skills, tax and financial incentives.

Table 3
Competitiveness analysis of Taiwan's machinery industry

S	W
• High quality manpower • Ample capital. • Good at duplicating, capable of catching up with the advances of rivals. • Well-built satellite factories with good support. • Good marketing information, quick response to market demands. • Ample tax and financial incentives from government. • Clustered industry structure. For example, the machine tool and woodworking machinery manufacturers cluster around central Taiwan, while the Tainan area is clustered with most of the plastic machinery manufacturers.	• Insufficient R&D. • Expensive real estate. • Insufficient skilled labor. • Shortage of system integration capabilities. • Undersized satellite factories. • Overreliant on imported equipment and key parts. • Unable to cut into the main industries (transport, semiconductors). Failing to get a hold on their key techniques.
O	**T**
• Increasing automation of production. • Mature electronic information industries may fully support machinery industries. • Gradually developing and producing key parts. • Global marketing channels and postsales services are getting set up. • Devalued New Taiwan Dollar (NTD) is an advantage in broadening markets. • The investment of R&D is increasing.	• Downstream industries keep moving away and so does demand. • Exporting market is not diverse enough (China and the States take up to 1/2.) • Investors have low interest in long-term investment. • China, Korea and Eastern European countries have begun to compete in Taiwan's markets. • Low costs from other producers damage attempts to broaden markets. • Government has less direct power as Taiwan joins WTO. • Operational risks are higher due to the unstable currency.

Data source: Bureau of Industry, MOEA, ''Development Strategies and Actions of Machinery Industry''.

As summarized in the SWOT analysis in Table 3 [13], the machinery industry also faces significant disadvantages. For example, certain key components depending on imports, insufficient investment in R&D, and large percent import of the key manufacturing equipment (e.g., semiconductor equipment). These problems have to be resolved. The facts that downstream businesses keep moving overseas and unbalanced a large portion of the exports concentrated in China and the United States also created the new problems and potential threats.

4. Analysis on forecasting results

This paper adopts the Delphi method. The forecast focuses on the development trend of Taiwan's machinery industry after 2010. The products with potential are included. The

experts are not allowed to interact with each other during the research process. This section presents and discusses the results of the forecast.

4.1. Forecast of the potential products

Three rounds of the questionnaire yielded 52 products recognized as having high potential. Those with an average growth rate over 10% were: linear motors (21.78%), high-speed cutting machine tools (19.9%), micromachinery (17.75%), linear guides (17.22%), PC-based controllers (16.7%), environmental protection machinery (15.33%), etc., totaling 27 items. The top 15 are listed in Table 4 along with their average growth rate.

Besides high-speed cutting machine tools and linear guides, coefficients of variation (CVs) for the leading 15 products are under 50. Estimated growth rate of high-speed cutting machine tool hits both 60% and 3% and fails to converge down to 50 after the third round. Optimists recognize high-speed cutting machine tools will be very popular products, while pessimists believe the growth rate of the entire machine tool industry will be below 5%. Optimists believe that linear guides possess a growth rate of 40%, while pessimists believe it has only 3%. After the three rounds, the CV still is 60 and fails to get below 50. Optimists recognize the trend towards high-speed will increase the demands for linear guides, while pessimists believe linear guides in Taiwan has limited growth space even if it is energy

Table 4
Top 15 machinery products with the greatest potential in 2010 in Taiwan

	Max (%)	Min (%)	Average (%)	Mid (%)	CV (%)			Q3–Q1
					1st Run	2nd Run	3rd Run	
Linear motors	40	5	21.8	20	53.1	47.9	44.4	20–25
High-speed cutting machine tool	60	5	19.9	16.5	86.9	71.1	74.5	13.5–20
Micromachinery	30	6	17.8	17.5	63.5	38.7	37.5	15.8–20
Linear guides	40	3	17.2	15	76.1	65.5	60.9	13–20
PC-based controllers	30	4	16.7	15.5	54.2	40.3	38.5	15–19.3
Environment protection machinery	30	4	15.3	15	70.3	62.4	50.9	12–15
All electric injection molding machinery	25	5	14.9	15	65.3	51.5	41.2	10–20
PC-based machine tool	20	5	13.2	12	49.0	46.0	34.4	11.3–15
IC rapid thermal processor	15	7	12.7	13		33.3	22.6	12.5–15
Industrial robots	20	4	12.6	13.5	69.7	47.1	37.9	10–15
Semisolid metal molding machinery	15	4	12.6	15	59.7	40.5	33.4	12–15
Medical care equipment	15	6	12.6	13		30.8	25.5	12–15
High pressure pumps	15	5	12.5	14		38.7	31.1	12.3–15
LCD manufacturing equipment	20	5	12.4	12	67.0	45.3	36.9	10–15
High-speed spindle	15	5	11.8	12.5		33.8	26.8	12–13

Max = maximum of the compound annual growth rate forecasted by experts. Min = minimum of the compound annual growth rate forecasted by experts. Average = average of the compound annual growth rate forecasted by experts. Mid = median taken from the list sorted according to the experts' forecast values. Coefficient of variation: $CV = s/\bar{x} \times 100\%$, where $\bar{x}$ is the average, s is standard deviation. Number of experts surveyed is 10. Q3: the third quartile; Q1: the first quartile.

Table 5
Top 15 machinery products of Taiwan and their opportunities, advantages and threats (tabulated opinions of 10 experts generated by the Delphi method)

	Opportunities	Advantages	Threats (with pessimistic views)
Linear motor	• Machine tool is becoming faster and more accurate. New technologies will replace the conventional indirect mechanisms.	• The info. Elec. and machinery techniques may support high-accuracy and high-power linear brushless motors and linear inducting motors.	• Taiwan has just started while other countries have been producing for 30 years.
	• Tremendous market demands and potential.	• Ample capital in Taiwan. Government assistance helps businesses stay involved.	• There are already competitive products in the global market.
	• Can comply with high-speed requirements and saving rooms.		
High-speed cutting machine tool	• Will become a future mainstream product with higher and higher growth.	• Healthy industry structure.	• Overall R&D capability is less than Japan.
	• Meets the needs from aerospace industries.	• Well planned and quick in upgrading.	
	• Will outphase moulds and bulky object.	• Government helps the industries tremendously.	
	• Needs in refining light alloys are increasing.		
	• Good opportunities in refining and thin-layer piece crafts.		
Micromachinery	• MEMS market revenue is estimated to reach US$30,000 million by 2005. Taiwan is to take up 3%.	• Similar production procedures to IC. Taiwan already has the preliminary foundation. Taiwan's manpower is cheaper than that of Japan, the United States and Europe.	• A 5 to 10 years technique gap between Taiwan and advanced countries.
	• MEMS is a prospective combinatory production technique of the 21st century. It is also the key technique for new product developments in Taiwan.	• Enthusiastic support from industry, governments, academics and research institutes.	• Prospective techniques are hard to acquire. Key patents are snapped up by other countries.
	• Gradually mature techniques. These possess potential in the areas of transport, medical care, monitoring, communication, automation, instruments and consumer goods.		• Good but unattractive products.

Linear guide	• The markets of automation and precision machinery seem to be prosperous.	• Good R&D combined with business investments.	• Most current machinery is imported. Machines made in Taiwan need improved accuracy and reliability.
	• Speed efficiency is becoming important and has growing potential.	• Ample capitals. R&D assisted by governments.	• More energy efficient than conventional slider bearing, friction rubbing resisting widely adopted. Limited growth expected.
		• The demands and profits on machine tool and IC equipment are increasing daily.	
PC-based controller	• Growth depends on the growth of Taiwan's machine tool. • Enhanced advantages may be achieved with Internet. • More people are willing to use the machines due to wide PC use. • Low cost, high reliability, convenient communication schemes.	• Several domestic investors involved. Market growth follows the growth of PCs.	• Strong competition from other countries.
Environ protection machinery	• The rise of environmental protection concepts is raising domestic demand. The imported products meet domestic requirements completely.	• Sufficient capital, and active government assistance.	• Size-limited domestic companies. Difficult to broaden markets and to develop techniques.
	• Market growth is expected due to the demands from environment protection regulations.	• Good foundations and manpower in mechanical, chemical and electronic engineering.	• Strong competition from foreign countries.
			• Most companies are small or middle-sized companies. They started very recently. The high-price end products are under the control of other countries.

(*continued on next page*)

Table 5 (*continued*)

	Opportunities	Advantages	Threats (with pessimistic views)
All electric injection molding machinery	• All electric machinery is expected to take up 50% of the market in 10 years due to the fast growth of mobile phones and thin notebook computers in 1999 and 2000, and the ISO 14000 environmental protection requirements.	• Good interactions with peripheral industries.	• Unable to domestically manufacture servomotors and controllers.
	• Continuous demands in high-accuracy injection parts.	• Good organizational capability and good ability to lower costs.	• High international competitions.
PC-based machine tool	• It is mature enough to take the advantage of the Internet for servicing functions.	• Taiwan is good at PC hardware support.	• PC-based machine tool is installed in large foreign factories.
	• PC-based machine tool may become outstanding along with the improved PC functions.	• There is sufficient PC manpower since Taiwan already manufactures PCs.	• Taiwan's factories are used to imported machines.
	• Very competitive in the mid- and lower-price end equipment, and prepared for the in-house factory network in the future.		• Increasing competition from China.
			• Costs increased due to European certification (CE).
IC rapid thermal processor	• This facility has tremendous impacts on contact formation, barrier layer formation, BPSG reflow and source drain anneals. In order to achieve 0.18-μm design base, super shallow surface attachment is to be the key to manufacturing.	–	• International competition.
			• Semiconductor manufacturers are picky in reliability. Multiple testing is necessary, otherwise it remains pessimistic.

Industrial robot	• Short-term market is saturated. Robotics is expected to be widely used in IC manufacturing procedures. • More requirements in land costs, manpower costs and working environments.	–	• Predicted growth is limited due to the production reliability and the quality of after services. • Good but unattractive products.
Semisolid metal molding machinery	• Increased demands in notebooks and communication equipment. • Large demands in aluminum and magnesium alloy, 3C, parts for transport facilities.	–	• Strong competition from other countries.
Medical care equipment	• Medical care needs increase once the medical insurance system is put in place. • Increased needs due to an ageing society.	• Technical capabilities have been acquired. • In contact with certification channels. • Placed on the priority list by government.	• Sales channels are still threatened.
High-pressure pumps	• To meet the needs from high-pressure cutting machinery, tall building fire extinguishing, high-pressure cutting.	–	• Potential market, but the capabilities need to be improved. • Small high-pressure pumps are inexpensive. • Immature techniques.
LCD manufacturing equipment	• Six LCD manufacturers invested more than 100,000 million NTD in the recent 2 years. • LCD production is growing and has strong needs in equipment.	• There is still room for improvements in the domestic and international techniques.	• Other countries own most patents. Japan holds most of the key techniques.
High-speed spindle	• Major key parts of machine tool with high potential. • Market demand increased due to speed-improved machine tool.	• Capable of handling the rework techniques. • Capable of inspection	• Needs to improve the techniques.

Table 6
Average growth rate of Taiwan's machinery industry production value

Year	Item							
	Max (%)	Min (%)	Average (%)	Mid (%)	Standard deviation	CV		Q3–Q1
						Run 1	Run 2	
1998–2000	5	5	5.0	5	0.00	14.37	0.00	5–5
2001–2005	8	5.5	7.25	7.5	0.80	23.54	11.06	7–7.63
2006–2010	9	5	6.94	7	1.21	35.84	7.42	6.38–7.25

saving, has high rubbing resistance and is widely used. These two products have a reasonable concentration tendency according to mid values and averages, meaning that the rest of the experts agree. Therefore, these two products are included in the top 15 growth-rate list. Table 5 lists the opportunities, advantages, and threats surrounding these top 15 products.

4.2. Production value

According to the forecasting results of 10 experts, the average annual growth rate is 5% for 1999–2000, 7.25% for 2001–2005 and 6.94% for 2006–2010 (see Table 6.).

The 1997 production value of Taiwan's machinery industry was US$12 billion according to Wang et al. (April, 1999) [14]. Taking this data and considering the growth rate of average production value, the overall Taiwan machinery industry production value is estimated to reach US$23,700 million as illustrated in Table 7.

The forecasting production value presented in this paper is based on the contracted number derived from the Delphi method by taking the historical data and available multiple interactive attributes into account. In the first place, before the survey was made, the background of Taiwan's machinery industry and its historical data were given to the team of the experts for their reference. Secondly, the forecasting to the production value from the team of experts was required to be made based on the interactive attributes in terms of its strength, weakness, opportunities, threats, and future potential directions for the Taiwanese machinery industry, as further elaborated in Table 5.

Among the top 15 products listed in Table 4, two products, namely, high speed cutting machine tools and linear guides, have a CV number larger than 50 indicating their greatest market potential. The other 13 products having the CV falling between 22 and 50 after three rounds of the contraction might be more controversial. The resulting low minimum value at 3.7% was attributed to the extremely pessimistic projection on the future growth rate among

Table 7
Forecast of Taiwan's machinery industry production value (unit: US$100 million)

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Rev.	120	108	114	119	128	137	147	158	169	181	194	207	222	237

Data of 1997 was the actual data given by Center of Mechanical Engineering, ITRI.
Data from 1998 to 2010 was forecasted by the Delphi method.

Table 8
Problems and recommended strategies on the future development of the top 15 machinery products in Taiwan

Potential products	Evaluations and suggestions		
	Development directions	Problems	Suggestions
Linear motors	• Avoid magnetic interference, focus on high power, and lower costs.	• Position control reliability needs improvement.	• Encourage private business involvement. Give tax breaks and financial support.
	• High-speed motion, high-speed material feed-in.	• Rely on imported products.	
High-speed cutting machine tool	• Develop high-speed spindle technique.	• High-speed spindle development in Taiwan is not yet complete.	• Introduce techniques from other countries.
	• Develop linear motor technique.	• Technical parts remain to be developed.	• Develop parts through technology development projects.
	• Networking between controllers and networks.		• Enhance technical collaboration with Japan and Europe.
	• High-intensity materials.		• Commercialize academic research products.
	• Enhance durability.		
	• Enhance rework efficiency.		
	• Sensitive toward the smaller feed-in.		
Micromachinery	• Intellectual sensing modules, momentum acceleration equipment, chemical sensing equipment, medical diagnosis equipment, micro actuator.	• Industry remains unfamiliar with these technologies, and they remain in a very preliminary stage.	• Follow the R&D development model of IC industry.
	• Intellectual minirobots.	• Not enough manpower in R&D design.	• Integrate capabilities of optical, mechanical, electronic, material and miniaturization techniques.
		• Need more training in development and design.	• Government support in R&D and manufacturing.
		• Key techniques are mostly owned with patents.	
Linear guides	• Increase the load capability.	• Lower-end techniques.	• Emphasize on development of manufacturing technology.

(continued on next page)

Table 8 (*continued*)

Potential products	Evaluations and suggestions		
	Development directions	Problems	Suggestions
	• Adopt permanent oil lubrication.	• Overreliant on imported machinery.	• Government should encourage key parts R&D, and also make financial and tax aids available to industry.
PC-based machine tool	• Place workstations and networks, build-up interfaces between human and machine (combined with CAD). Lower prices.	• Lack economic scale.	• Enhance the portion of production made in Taiwan and decrease imported machines.
		• Not enough manpower in integrating servosystems.	• Improve the vertical loads shared with China.
		• The market of PC-based controller is dominated by Europeans and Japanese.	• Improve controller reliability.
			• Improve reliability and safety.
			• Enhance servomodule stability.
			• The mechanism for after service ought to be completed.
			• Enhance networking.
Environmental protection machinery	• Solid trash treatment equipment (community trash treatment, special vehicles, recycling, trashed appliance, trashed car, PCB).	• Need to improve waste water and trash treatment techniques.	• Techniques ought to be rooted and developed locally.
			• Look for international cooperation partners, and take advantage of technology development project to break through the bottlenecks.
			• Make trash collection trucks and trash furnaces in Taiwan with the aid of regulations.
			• Industry, government, academies and research institutes need tocarry out system integration.

			• Speed up the production technologies of the environmental protection industry in the short term. • R&D on special purpose equipment.
All electric injection molding machinery	• PLC control, human machinery interfaces. • Controllers, high-precision screws. • Servomotor is the key item.	• Key parts rely on imports.	• Speed up research on servomotors. • Use technology development projects to breakthrough bottlenecks of key parts. • Capacity and production tons should be increased.
PC-based controllers	• Multifunction. • Integrate with CAD. • Replace some of CNC controller.	• No standard. • Feature cannot compare with foreign product.	• Enhance development on software.
IC rapid thermal processor	• Heating evenness, repeatability and heating rates.	–	• Clarify the heat radiation characteristics of the materials. • Introduce proper temperature control equipment.
Industrial robots	• Suitable for clean rooms and vacuum chamber. • Fast, user friendly, small footprint, inexpensive, free human attention.	• Need to improve the system application management capability.	• Develop key parts in Taiwan. • Look for international cooperation partners. • Take advantage of technology development projects to breakthrough bottlenecks. • Increase the loads.
Semisolid metal molding machinery	• Make high-accuracy and smooth surface molding machinery the mainstream products.	–	• Need to enhance the mould capability. • Emphasize R&D of key parts. • Emphasize R&D of key parts.

(continued on next page)

Table 8 (*continued*)

Potential products	Evaluations and suggestions		
	Development directions	Problems	Suggestions
Medical care equipment	–	• Inspection system needs to be built up.	• Need to combine mold and manufacturing techniques. • Need to increase the capacity and production tons. • Maintenance techniques need to be improved. • Establish an inspection system. • Acquire product certification and sales channels.
High-pressure pumps	–	–	• Pressure should increase from 20 to 70 kg/cm^2. • Need to overcome the problems in duration and sealing in high-speed pump.
LCD manufacturing equipment	• Equipment for larger LCD (14 in. and above).	• Must integrate mechanical, electronic, chemical, optical and material experts. • New manufacturing techniques need to be introduced.	• Work together with R&D experienced companies in Taiwan. • Push user and maker sign for strategy alliance via special research project. • 1st step — strategy alliance with other countries; 2nd step — develop key parts.
High-speed spindle	–	• High-speed spindle is the key part of machine tool, yet the technology does not exist in Taiwan.	• Actively invest in R&D techniques. Technologies may be introduced or may be acquired via co-operation. • Must simultaneously develop high-speed bearing, lubrication, cooling.

the two or three experts. They believe that most of high-technology products such as precision tools and semiconductor production equipment in the Taiwanese machinery industry are to be suffered in the strong competition from Japan and the US, who could provide the qualities of high precision and high stability. It is truer in the semiconductor industry in which the minimum downtime of the production could be assured by the high-quality products. The successful challenge to face the competitions from Japan and the US is not expected.

On the other hand, the optimistic experts are expecting the strategic alliance with the global major competitors complementary to the low production cost and the enriched capital in Taiwan. The joint efforts could be made in developing the key components, parapherical products and related maintenance business. Taiwan could easily become one of the chain suppliers in the global business. The intensive basic and applied research, in the meantime, should be emphasized along with the appropriate government incentives and available easily accessed venture capital.

5. Conclusions and suggestions

After three rounds, we know that Taiwan's machinery industry may reach US$23.9 billion. The forecasting indicates the top 15 products with the highest average growth rate

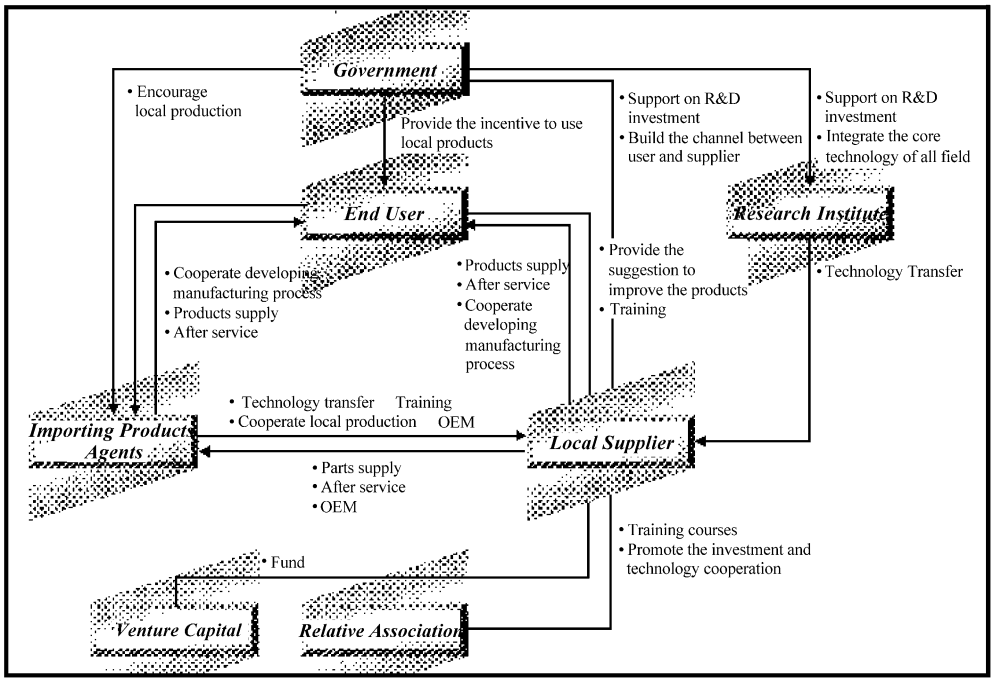

Fig. 2.

are: linear motors (21.8%), high-speed cutting machine tools (19.9%), micromachinery (17.8%), linear guides (17.8%), PC-based controllers (16.7%), environmental protection machinery (15.3%), all electric injection molding machinery (14.9%), PC-based machine tools (13.2%), IC rapid thermal processor (12.7%), industrial robots (12.6%), semisolid metal molding machinery (12.6%), medical care equipment (12.6%), liquid crystal display (LCD) manufacturing equipment (12.4%), and high-speed spindle (11.8%). Table 8 presents that the above top 15 machinery products with great potential market could be considered as the major business development directions and references for the government policy decision in resources allocation. The detailed discussion for each product is available in the table.

As to the government funding research, it is suggested that more efforts should be made on developing linear motors, high-speed cutting machine tools, micromachinery, linear guides, and PC-based controllers.

The recommended strategies on how to do the coordination among the private sectors, venture capitals, research institutes, and the government for Taiwan's machinery industry is also illustrated in Fig. 2. A well-integrated structure to link the government-related resources and different pools in the private sectors with their relative strengths could assure the success of joint efforts in the machinery industry development for the next 10 years.

Appendix A. Questionnaires survey for future development trends of the Taiwan machinery industry

Industries or products with development potential	Compound annual growth rate (%)			Depictions (Opportunities, competition, threat.)	Problems and strategies in the future
	1998–2000	2001–2005	2006–2010		
1. Machine tool					
(1) Six axial machine tool					
(2) PC-based machine tool					
(3) High-speed cutting machine tool					
(4) RPT					
2. Electronic industry equipment					
(1) PCB equipment					
(2) SMT equipment					
3. Wafer process equipment					
(1) CMP					
(2) Dry cleaning equipment					
(3) Etching equipment					
(4) Sputtering equipment					

4. Packaging process equipment
   (1) Die bonder
   (2) Wire bonder
5. Molding machinery
   (1) All electric injection molding machinery
   (2) Semisolid metal molding machinery
   (3) Planetary extruders
   (4) Bi-oriented film extruders
6. Molds
   (1) Injection mold (for disc, magnesium alloys, etc.)
   (2) Press mold (for lead frame, precision process, etc.)
7. Food-processing machinery
   Bacteria free packaging equipment
8. Transport machinery
   Reducer for elevators
9. Packaging machinery
   Automatic packaging integrating systems
10. Textile equipment
   (1) Shuttleless weaving machinery
   (2) Industrial sewing machinery
11. LCD manufacturing equipment
12. Micromachinery
13. Environmental protection machinery
14. Industrial robots
15. Precision parts
   (1) Scroll compressors
   (2) Vacuum pumps
   (3) Mass flow control valves
   (4) Proportional valves
   (5) Precision bearings
   (6) Planetary gears
   (7) Linear guides
   (8) Linear motors
   (9) CNC controllers
   (10) PC-based controllers

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