WORKING PAPER

THE WORLD AUTOMOTIVE INDUSTRY IN TRANSITION: A FRAMEWORK FOR PROJECTION INTO THE 21ST CENTURY

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IIASA
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A-2361 Laxenburg, Austria

PREFACE

The world automotive industry is currently in the midst of major transitions involving substantial changes in the design, production and distribution of the automobile. Technological innovations involving microcomputers and robotics have changed the industry's concepts of what constitutes an economically feasible product; global economic structures and constraints have modified the industry's view of how the automobile should be produced; the social and political environment have forced major industry reexamination as to what type of car will serve the world's needs over the coming generation.

The automotive industry transitions can be seen over two rather distinct time horizons: a "short-term" phase, extendind over the next 20 years or so, and the "long-term" horizon of the coming 20-50 years. With each of these time periods, we can identify a central issue for the industry encompassing many technical, economic, environmental and sociopolitical subproblems.

For the short-term, past decisions and capital investments have committed each of the world's manufacturers to a production and marketing strategy that they will have to live with to the turn-of-the-century. It is possible to identify a set of qualitatively and observably different basic strategies and each manufacturer has selected a particular plan from this set. The crucial question that arises is what strategy or combination of strategies will ultimately prevail over the coming decades? The current high level of uncertainty in the automotive industry revolves about the answer to this question, since each strategy implies fundamentally different views of the overall process of providing personal automotive transport. As the auto industry proceeds to the 21st century, the firms continue to engage in a multi-party semi-cooperative game, with the successful strategies dictating the shape of the industry at the close of the century. Thus, the overriding short-term question is the determination of those strategies which would be most likely to succeed and what the implications are of each strategy for the structure and operation of the industry at the end of this century.

Over the "long-term" (20-50 year) horizon, the key auto industry question is whether the development of a "top-down" functional view of the automobile will replace the current "bottom-up" component view. This is a systems problem, not very much different in character from the type of questions encountered on evolutionary development: a set of functional requirements for an automobile is prescribed (e.g., safety standards, fuel consumption requirements, pollution levels and so on), and a set of procedures is invoked in order to characterize feasible designs meeting the functional specifications. A *selection mechanism* is then employed to single-out the "good" designs on the basis of their "fitness" for the operating environment. This is a holistic, global approach to the automobile; the only problem is that the procedures available at present for characterizing feasible configurations are very poorly developed, and what is worse, there is no understanding at all of how to introduce a good measure of fitness for an automobile in a particular environment. Consequently, current procedures employ a standard reductionistic approach of designing the individual components (e.g., motor, body style, exhaust, etc.) separately, then attempting to fit them together into the overall product. However, all indications are that increased utilization of computer-aided design procedures and external economic, social and political pressures will increasingly push the automobile industry away from the reductionist to the holistic mode in its product-design approach.

The structural-to-functional philosophy is not peculiar to the automotive industry. In principle, it applies to all industrial enterprises where the digital computer is playing an important role in the overall product design, i.e., it applies to virtually every industry. Consequently, we argue that the auto industry should be viewed as a specific instance of a mass-produced item undergoing evolutionary transition in its design, production and marketing procedures, and that such a study will lead to the more general systems phenomena underlying this evolutionary development. The ultimate goal of an investigation of this sort is to understand the design generation and selection mechanisms and their implications for reconfiguration of the industry. To effectively approach such a general question, it is necessary to deal with the shorter-term competitive strategies, as well as delve into almost every aspect of automotive technology, production and distribution. Despite the impressive work analyzing the world auto industry by other groups, such as MIT and the EEC, as yet there has been no study combining a long-term perspective (20-50 years) with a global view involving the developing world, utilizing an analytic framework of investigation. This report outlines the background material and provides a perspective and a research program for such a study.

To summarize, a global, long-term study of the world automotive industry remains to be carried out and would contribute to satisfaction of the following general objectives: (i) a deeper understanding of the processes and patterns surrounding structural and evolutionary change in industry; (ii) a thorough investigation of an industry which is central to the economies of almost all industrialized and many developing countries; (iii) a study whose intellectual content cuts across a large number of important themes including energy, adaptive policy design, optimal resource utilization, demography, urban dynamics, environmental pollution and international trade.

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1. WORLD AUTOMOTIVE INDUSTRY: ISSUES AND PROSPECTS

1.1 From Growth to Stagnation

The automotive industry has experienced a phase of very rapid growth since its inception in the 1900s with average annual growth rates well in excess of 10 percent. In the mid-1970s, however, the industry has reached a new phase of development. The former president of Mercedes-Benz, Professor Joachim Zahn (1976), five years ago anticipated already that a phase of low growth and large fluctuations of the total volume of automobile sales had begun. Especially in North America and Western Europe, the production volume is now fluctuating around a stagnating trend and in the UK, the US and even Japan, declining rates are observed, while the rest of the world's industry is in a phase of initial development, with the first signs of an emerging automotive industry observed in Spain, South Korea, and to a degree in the USSR and Eastern Europe, as well.

Figure 1 illustrates the world development, indicating that the total production more than quadrupled between the 1950s and 1970s, while it remained almost constant during the last five years. This development of the total volume of production is not unique to the automotive industry; it is typical of most industrial products: after a long phase of exponential growth, the market appears to be saturated and the total volume of production fluctuates around a stagnating trend. Perhaps the best known example of such a development is the production of steel and basic minerals, including energy sources such as coal and crude oil. This situation puts much stress on the industry that did not exist during the growth phase--capacity

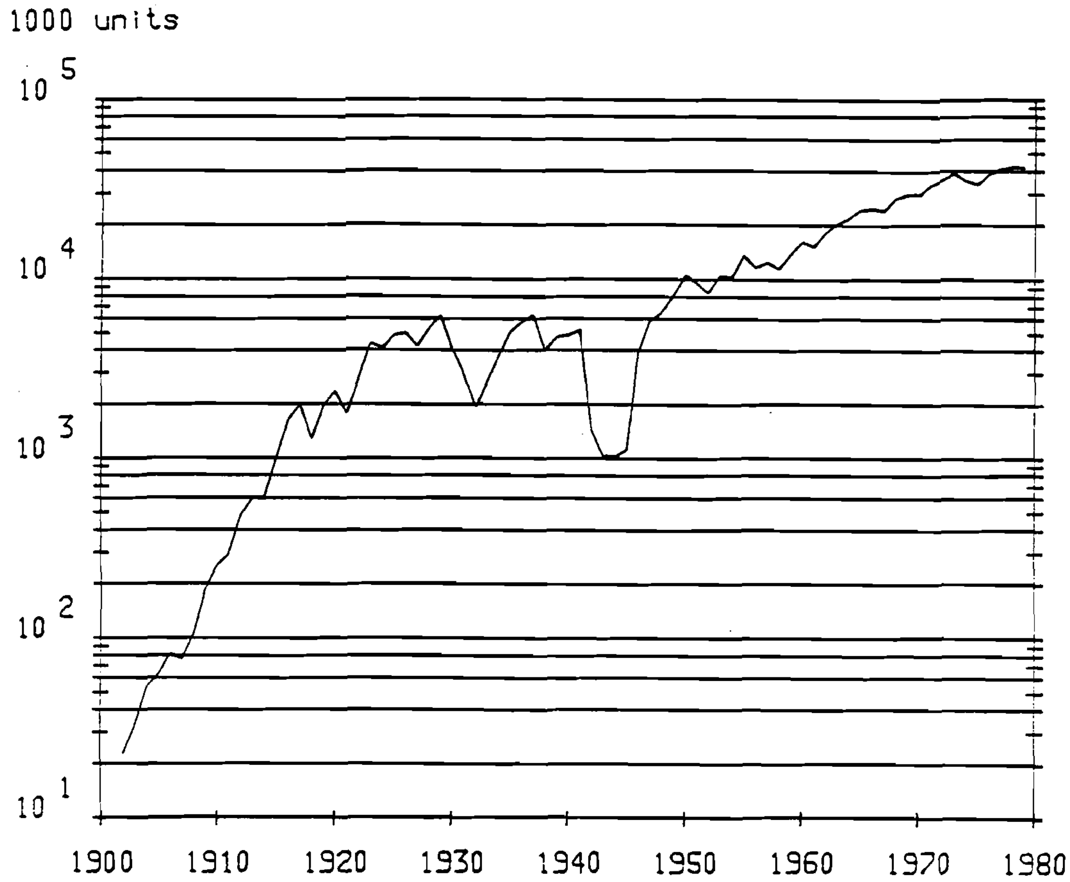

Figure 1. Motor Vehicle Production, World. Source: World Motor Vehicle Data (1980).

utilization is low, especially during the down-swings and inventories are large because of the uncertain and fluctuating market conditions. This fact alone tends to create higher capital needs, stronger competition and lower labor demands.

1.2. From National to Global Industry

Thus, while these oscillatory aspects of the recent development of the automotive industry are not unique, they have led to a unique transition of the industry in the world at large. This transition may turn out to be indicative of what could happen in other industries, but even on its own merits it warrants further consideration. Perhaps the most important single aspect of this transition is that it will integrate the automotive industry from national ventures into a truly global operation. While it is true that the industry has been oligopolistic in nature for at least 50 years being dominated by large corporations that controlled both the production and marketing of their products, although some of the corporations were international (e.g., GM and Ford), their national operations were almost independent from one country to another. Only recently can the first signs be recognized of the international nature of the automotive industry. The typical and distinctive "characteristics of national oligopolies are now evident internationally" (Bloomfield 1981) and will slowly give way to new "global" characteristics of the industry and its products. This has led to the development of "world-cars" (a term used by US manufacturers), a product range that is offered worldwide with changes for each country to suit local regulations and conditions. All major firms are intensifying their international operations and foreign ventures in order to "smooth-out" local market fluctuations and expand the scale of their operations. This trend has intensified the oligopolistic competition previously experienced only at the level of national markets.

1.3 The Future of the Automobile

The increase of fuel prices during the 1970s and the uncertainty about the future availability and form of automotive energy sources have not only added a major new component of research and development throughout the automotive industry, but have also initiated a change in the public perception of the automobile. In the 1950s and 1960s, power, performance and comfort were the advertised and appreciated qualities of a motor vehicle; today fuel efficiency, economy and safety are the commonly heard and advertised qualities. The design and production of a more efficient automobile with lower environmental impacts and safer dynamic and passive characteristics are the main objectives of all large manufacturers. These are in part conflicting objectives, some of them being reinforced by government regulations, so that their reconciliation and fulfillment necessitates the design and development of both new products and production facilities.

The automobile industry and its products are undergoing a phase transition from the traditional structural design of the vehicle (e.g., with emphasis on horsepower rating, styling, etc.) to a functional design procedure (where components are specified in terms of the overall objectives). This issue of a top-down functional design approach will be addressed specifically in Section 2. Now we consider the changes in the automobile itself and in the industrial structure that are either already underway or are expected in the very near future.

1.3.1 Efficiency

One obvious way to achieve more fuel efficient vehicles is to make them lighter, since the fuel consumption of an automobile is proportional to its weight at low speeds, all other things being equal. Weight reductions can be achieved by downsizing, however this is obviously only a limited measure especially for small cars.

Other weight savings can be achieved by the use of alternative structural materials and design. Obvious candidates are aluminum and light alloys, but also carbon and glass fiber epoxy materials. Light-weight structural designs can be achieved, e.g., through the use of honey-comb structures and finite-element design analysis, etc. Finally, new propulsion and drive systems can also save weight, including the use of ceramics and light alloys. For example, front-wheel-drive cars can be made much smaller with the same passenger compartment size than rear-wheel cars at the expense of more complex assembly and maintenance.

A fundamentally different method to achieve more fuel efficient vehicles is to lower the drag of the car by decreasing the surface and internal friction of the vehicles. The first measure that is becoming very popular these days is to improve the aerodynamic qualities of the car by reducing the so-called C_d value. Other measures include lower roll resistance of the tires and lower internal friction of the propulsion system (e.g., of the bearings, oil, disc brakes when not engaged, etc.).

The last approach includes improvements in the propulsion system and its control. Such measures range from improved fuel efficiency of conventional engines all the way to completely new ideas such as the hydrogen (Peschka 1981) and liquid air propulsion systems (Marchetti 1976; Dooley and Hammond 1982) of the more distant future. In this regard, high temperature ceramic and metal alloys will play an increasing role in improving the thermodynamics of the combustion engine, together with more intensive use of microprocessors for the closed-loop dynamic engine and drive-train (e.g., transmission) control.

1.3.2 Environmental impacts

Some of the measures directed at efficiency improvements also lower the adverse environmental impacts of the automobile. Lower fuel consumption per kilometer, *per se*, lowers the impacts by lowering the specific primary energy needs. However, there are also some adverse environmental effects of improving the efficiency of the internal combustion engine. For example, although a more efficient gasoline engine burns the fuel mixture more completely so that the relative share of HC and CO emissions by volume is lower compared to a less efficient engine, it produces at the same time a larger share of NO_x emissions so that (catalytic) three-way afterburns become necessary (Bruce-Briggs 1977).

The air pollution of future automobiles may also be reduced by use of alternative energy carriers. We have already mentioned hydrogen-powered internal combustion engines and expansion of liquid air in a steam-engine type of power plant as possible candidates. Electric propulsion and many other potential alternatives can be added to this list. All of these energy carriers have virtually no exhaust emissions. However, they only transfer the environmental problems from the vehicle to the power plant where the energy carrier (e.g., hydrogen or electricity) is converted from an energy source. Thus, the requirements of better fuel efficiency and lower exhaust emissions are at least, to a degree, mutually exclusive for spark ignition and diesel engines.

However, exhaust emissions are not the only adverse environmental impacts of the motor vehicle. The list is very long, ranging from construction of traffic systems (e.g., roads) to material requirements of the automotive industry, and resulting impacts of materials mining and processing. In 1969, the US automotive industry accounted for 42 percent of all US iron (malleable) consumption, 10 percent of aluminum, 33 percent of zinc and 72 percent of natural rubber (Leach 1973). With current trends it should be expected that the share of energy intensive materials will increase, especially the use of aluminum and light metal alloys. The same would be the case for carbon fibers, plastics and electronic equipment. At the same time, these high requirements of natural resources are also a benefit, since the automotive industry generates along with resource consumption considerable employment and economic activity directly and through its suppliers.

1.3.3 Safety

Automotive safety is one of today's major public concerns. Safety measures include design procedures by the manufacturers, along with public measures such as safer roads and regulations, better training of the drivers and so forth. The safety measures of the automobile itself can be divided into active and passive types. Active measures and systems help to avoid accident situations in which they are likely to occur. Passive measures are directed toward preventing injury of an occupant during the accident. Thus the passive measures are directed primarily toward improving the impact absorption characteristics of the automobile (stronger cars that are "softer" outside) and restraining the passenger from hitting any parts of the interior during an accident (padded interior, seat belts, air-bag). Active systems range from better car stability, braking (e.g., anti-skid) systems and better driveability through simpler instruments, control systems and general car design. Here there is considerable room for new electronic equipment, such as better driver information systems (on car and traffic status) and simpler car control.

1.4 Industry in Transition

The continuing pressures to develop more efficient and safer cars are coinciding with market saturation in the industrialized countries with the effect of low corporate earnings and large excess capacities. We have already outlined above that the development of more efficient automobiles with lower environmental impacts and better safety measures poses many conflicting objectives, some of them being reinforced or even dictated by government regulations, so that their reconciliation and fulfillment necessitates large investments. In times of low earnings and unutilized production capacity, high investment requirements in new products and production facilities accentuate the differences between the more and less successful companies. Furthermore, large investments in a single product are not only risky (e.g., if the public turns out not to accept a new design), but also necessitate very large production volumes. They can be recovered only if the development costs and investments are low per unit of production and the advantages of increasing returns to scale are fully utilized. Thus, the more successful companies are extending their scale of operation to fully global levels by offering virtually the same vehicles worldwide.

1.4.1 Economies of scale

The size of investments in new ranges of vehicles and production facilities is astounding. For example, it is estimated that GM, the world's largest manufacturer, spent about $1.5 billion in direct development costs for its X-bodied compact series introduced in 1979 and an additional $1 billion for tooling and facilities (Automotive News, 12.03.1979). In total, GM committed more than $13 billion for international investment in the 1978-82 period (Doz 1981). Thus, such expenditures clearly commit GM to become a truly worldwide competitor. Similar developments can be observed throughout the industry.

Integrated production and distribution operations across borders and continents are perceived as means of absorbing the high development costs and achieving large economies of scale (i.e., low costs per unit). According to Doz (1981) and Bloomfield (1981) the same forces of change will also tend to increase the minimum efficient scale reinforcing worldwide competition. Recent studies (see p. 375 in Bloomfield 1981) indicate that the size of operation needed to exhaust all significant economies of scale in the manufacturing is about 2 million similar units per year for metal stamping (body) and casting (mechanical components), 1 million units for machining of power train (engine and transmission parts) and more than 1/4 million for final assembly. The critical overall size for producers offering a range of models is between 1 and 2 million annual production capacity with about 80 percent long-term capacity utilization. This, however, is the critical minimal capacity. It should be noted that doubling production rates may cut total unit costs by 5 percent--the current low profit margin (at about 2 to 5 percent before taxes) makes that difference very important. A doubling of production from 1/4 to 1/2 million units annually may shift a firm from losses to substantial profits. Typical production rates today are lower than 1/2 million units per year in Western Europe (except Fiat) whereas they are substantially higher than 1 million in the US and Japan.

Marketing advantages and use of robots may offset to some extent insufficient economies of scale per single model line over a wide range of models (e.g., through sharing of components, or producing a car that exactly fits the needs of a customer at a higher cost). In fact, one of the important concerns of the manufacturers in the face of more intensive competition worldwide is to retain a network of good and reliable dealers. To strengthen the loyalty of the exclusive dealership, manufacturers are forced to produce a broad product range covering all volume segments of the market (Doz 1981). This suggests not only the need to manufacture a broad product range at a cost of lower production volume per model line, but also the need to maintain separate brands following mergers or acquisitions. Opposing this trend is the convergence of product specifications of the future automobile among different national markets that was discussed above. The convergence of product specifications (due to aerodynamics, weight-savings, etc.) actually imposes another problem on the manufacturers--the maintenance of the specific brand image and the corresponding market "niche". For example, Audi (a subsidiary of VW) conducted an extensive consumer poll to determine whether its new product, Audi 100 (Audi 5000 in the US), could be recognized by sampled consumers as an "Audi" without the help of badges (Car, October 1982). Thus the economies of scale in production and distribtuion impose conflicting objectives.

1.4.2 Productivity and adaptability

In order to decrease the unit costs and reconcile some of the conflicts involved, all corporations have been conducting critical evaluations of their model ranges, organizational structures, production facilities, productivity levels, standardization and automation levels and marketing methods to name but a few critical areas. In many cases the result of such evaluations was the closure of inefficient production facilities or their sale, with in some cases older facilities being replaced by more efficient ones producing a large volume of parts with worldwide distribution. Typical examples are joint ventures to produce a certain line of engines or straightout sale of automotive components to other manufacturers. Thus, greater standardization of methods and parts can affect substantial internal cost savings. This again allows for productivity gains through automation and robotization of production, which both increase the quality of products and achieve critical labor force reductions. These shifts in manufacturing style in turn require very large capital investments, so that the risks of investing in a wrong product line become larger and larger. Thus, increased use of "learning" robots is almost a requirement, since they can be retrained for different product ranges in the event of rapid market transitions. In addition, by virtue of their flexibility, the robots effectively offset some of the economies of scale difficulties because they allow the production of many different product versions within the same production process. It appears that only robots can provide substantial productivity increases and adaptability to new market situations.

Such productivity increases are crucial, even though direct labor costs represent only about 10 percent of the cost of a finished automobile, since the unit margins are so low that even slight savings on variable unit costs have a large impact on net profits.

Thus, Western Europe and especially North America have become more vulnerable to lower cost competition, primarily from Japan, but also from other countries. Recent progress in methods of shipping vehicles has made supplies from lower cost countries attractive. Therefore, the increases in productivity through appropriate scale of operations, increasing robotization and achievement of high adaptability to new market situations are imperative for the survival of every large manufacturer.

1.4.3 Integration and retreat strategies

There appear to be essentially three strategies in achieving productivity increases through new production methods. The first possibility is to integrate all international and domestic operations into a single worldwide undertaking. This strategy is especially appropriate for multinational corporations that are in a position to generate enough capital for the necessary development of new products and advanced production facilities. A typical example of this kind of approach is Ford's and later GM's integration of their national operations into a single global operation involving the production and marketing of "world-cars". Ford already offers three product lines of this new generation of cars: Fiesta, Escort and Sierra, and GM the X- and J-body cars. A variant of this approach for strong national corporations is to extend their domestic production overseas and consequently to expand an already integrated organization internationally. Typical examples of this approach are the large Western European firms such as VW or Renault and more recently also Japanese corporations.

A second approach is to retreat from some markets by selling single production facilities or whole operations and then to consolidate the product range and production method in order to achieve higher productivity. The advantage of this strategy for financially weaker corporations is that the sale not only brings about a necessary elimination of unprofitable operation, but it also helps to support new investments by generating additional cash-flow. Typical followers of this approach are the large, ailing firms such as Chrysler and British Leyland.

The third approach involves mergers and joint ventures. We have already mentioned the advantages of joint ventures and mergers for corporations which lack the necessary resources for truly global operations, or for those whose expansion is prevented by their national character or very limited market segments. Typical examples of mergers are the IVECO (1974) truck holding company, Volvo-DAF (1975) and Peugot-Citroën, which subsequently acquired Chrysler Europe (now called Talbot, 1979). Other examples are the Fiat-Lancia-Ferrari merger, the establishment of British Leyland and the VW-Audi-NSU merger. Joint ventures, or "quasi-mergers", are usually limited to cross-supply or joint marketing and they usually retain the independence of the partners in other respects. Typical examples are the use of VW engines by Chrysler, the SAAB and Lancia (Fiat) agreement to develop a joint car design (1979), the British Leyland and Honda joint production scheme and SAAB's use of Ford engines.

Continued development toward greater integration of the automotive industry throughout the world either through acquisitions, mergers or joint ventures appears to be unavoidable vis-à-vis the requirement of large investments in the development of new, more efficient, safer and environmentally compatible vehicles and the large investments in production facilities and methods that result in large productivity gains. Table 1 illustrates the high degree of interdependence of the Western European auto industry by showing the ownership links between the manufacturers. In view of such increased competition through integration and market saturation in the industrialized countries, a successful corporation must either grow rapidly, and so increase its economies of scale, or specially carefully in order to maintain its market "niche" and its position in the industry. This development is expected to bring higher economic efficiency and more efficient automobiles, but at the same time it has many adverse impacts in some parts of the world with respect to questions of balance of payments, unemployment and other economic issues.

Table 1. Interdependencies of Western European Firms (Source: W.J. Adams, 1981).

Producer	*Controlling company or government (31 Dec. 1979)*
Alfa Romeo S.p.A.	Italian Government
Audi NSU Auto Union AG	Volkswagenwerk AG
Automobiles Peugeot	P.S.A. Peugeot-Citroën
Automobiles Citroën, Société Anonyme	P.S.A. Peugeot-Citroën
Bayerische Motoren Werke AG	
BL Cars Ltd	British Government
BL Ltd	British Government
Chrysler España S.A.	P.S.A. Peugeot-Citroën
Chrysler France S.A.	P.S.A. Peugeot-Citroën
Chrysler United Kingdom Ltd	P.S.A. Peugeot-Citroën
Citroën Hispania	P.S.A. Peugeot-Citroën
Daimler-Benz AG	
Engins Matra S.A.	P.S.A. Peugeot-Citroën
FASA-Renault	Régie Nationale des Usines Renault
Ferrari S.p.A.	FIAT S.p.A.
FIAT S.p.A.	
Ford España S.A.	Ford Motor Company
Ford Motor Company Ltd	Ford Motor Company
Ford Nederland N.V.	Ford Motor Company
Ford Werke AG	Ford Motor Company
Lancia S.p.A.	FIAT S.p.A.
Nuova Innocenti S.p.A.	Italian Government
Officine Alfieri Maserati S.p.A.	Italian Government
Adam Opel AG	General Motors Corporation
Porsche AG	Volkswagenwerk AG
Régie Nationale des Usines Renault	French Government
Rolls Royce Ltd	
SAAB-Scania AB	
SEAT SA	FIAT S.p.A.
Sociéte des Automobiles Alpine Renault	Régie Nationale des Usines Renault
Volkswagenwerk AG	German Governments, Federal and State
Volvo, AB	
Volvo Car BV	Volvo, AB

1.4.4 Government control and subsidies

Government policies have always had a decisive impact on the shape and structure of national industries (Stubbs 1979). Consequently, in addition to consumer taste and local market conditions, government policy is also responsible for the national scope and distinctive characteristics of the automobiles offered in a given country, with tariffs and quotas exercising effective import control.

The first creation of larger, integrated markets occurred with the implementation of the EEC. As a result, trade became completely free within Western Europe and the norms and standards guiding automotive production were unified for most of the components (Doz 1981).

Today, both North America and Western Europe represent almost totally open markets with few tariff barriers. This means that these markets are easily accessible to low-cost vehicles from other countries, especially after the recent lowering of shipment costs. As a result, in some cases the national producers are seriously threatened by imports in addition to their mutual competition. This kind of a "weak home base" is especially critical in the UK and Sweden and is also becoming alarming in the US.

The negative effects of such development for the concerned countries cannot be overemphasized. It should be noted that in the EEC 5 percent of the employed labor force is engaged in the automotive industry directly. Taken together with indirect employment (e.g., in supplier-industries, services and government) this percentage is at least twice as large (Adams 1981).

In the US the share may be even higher, with some estimates indicating that 20 percent of the work force are engaged in automotive manufacture, sale, maintenance, services and roadways (Dooley and Hammond 1982). In view of these figures, it is obvious that one of the primary concerns of government policy in the industrialized countries is to maintain high employment in the automotive industry by opposing the downward pressures on domestic production volume. At the same time, such measures are directed toward the improvement of balance of payments since they tend to increase exports and decrease imports.

Opposing this government objective is the prerequisite for the domestic industry to increase its competitiveness through productivity increases and higher adaptability to market fluctuations and changes. Basically this means higher investments in robots which in turn lowers the labor participation in the production process. The problem is further compounded by the internationalization of manufacture and distribution. The concept of a "domestic" car is increasingly harder to define and the difference between domestic production and captive imports is disappearing, making government intervention and control either ineffective or impossible. Some of the recent trends in "free markets" are toward increased government participation in capital investments in new production facilities in order to attract domestic production. Typical examples are GM's drive-train production near Vienna, Ford's Fiesta assembly in Spain and the ill-fated De Lorean factory in Ireland. Thus, governments are being forced to subsidize industry in order to maintain employment and at the same time participate in investments that generate some new employment but also accelerate the phase of labor replacement by capital intensive means of production (e.g., robots and electronic equipment).

1.5 Spatial and Temporal Scope

In spite of the fact that the world automotive industry is entering a phase of increased global integration and interdependence of national markets, there are still large differences between various parts of the world with respect to the level of development of the automotive industry and the volume of the respective markets. For our purpose it will suffice to outline four broad regions of the world that have similar automotive markets and industrial structure. These four regions are by no means homogeneous and are not characerized by the geographic proximity of the individual countries, but they do help to describe different stages of global automotive development.

Region I consists of OECD countries and includes the major car-consuming and producing areas--Western Europe, North America and Japan. Region II includes the Soviet Union and other European Socialist countries. Region III consists of developing countries that have some (usually rapidly growing) automotive industry--for example, Brazil, Nigeria, South Korea and India. Region IV consists of developing countries that have virtually no automotive industry.

The transition to a stagnant, domestic automotive market is expected to affect mostly Region I and probably more North America and Western Europe than Japan. The demand for automobiles will probably continue to increase in Region II in the near future, whereas in Regions III and IV it could increase in a more distant future. At the same time, the production of automobiles will probably increase more rapidly than demand, especially in Region III. Region II, on the other hand, already has substantial production capacity. It is noteworthy that the major portion of this production capacity consists of turn-key plants designed by automotive corporations from Region I (cf. Table 2). In particular, the Soviet manufacturers of Lada and Niva cars have already achieved a substantial share of the off-road market sector in Region I. Even today, the captive production in Region III by Region I represents the major portion of its total production and in the future this trend can only be expected to continue and even extend to Region IV as the manufacturers continue the quest for cheaper labor. The list of these examples is by no means exhaustive, but it indicates that the demand for automobiles and their production will develop differently in the four broad regions of the world under the overall global transition toward increased integration and intensified competition. One of the important questions of this global transition is actually whether

Table 2. Examples of the Transfer of Western Technology to the Socialist Passenger Car Industry (as of 1980) (Source: J. Wilczynski 1980).

Western Licensor*	Socialist Licensee Country	Production Technology Involved (and year of agreement)
Citroën (Fr)	East Germany	Car parts (1978)
Citroën (Fr)	Romania	Citroën cars (1977)
Citroën (Fr)	USSR	Modernization of Moskvich (1978)
Fiat (It)	Poland	Fiat cars (1965, 1971, 1977)
Fiat (It)	USSR	Fiat cars (1966, 1978)
Fiat (It)	Yugoslavia	Fiat cars (1954, 1967)
Goodrich (US)	Yugoslavia	Tires (1974)
Kléber-Colombes (Fr)	Yugoslavia	Tires (1974)
Knorr-Bremsen (WG)	USSR	Brakes (1971)
Lucas (UK)	Czechoslovakia	Direction indicators (?)
Pirelli (It)	USSR	Rubber fittings (1967)
Renault (Fr)	East Germany	Modernization of car production
Renault (Fr)	Romania	Renault cars (1966)
Renault (Fr)	USSR	Modernization of Moskvich (1968-1970)
Renault (Fr)	Yugoslavia	Renault cars (1971)
SNIA-Víscosa (It)	Poland	Nylon cord for tires (1972)
Suspa-Federungstechnik (WG)	Yugoslavia	Shock absorbers (1973
Volkswagen (WG)	Yugoslavia	Volkswagen (1973)

*The parent country given in brackets: Fr = France, WG = West Bermany, It = Italy, UK = United Kingdom, US = United States.

we can expect the broad introduction of the automobile in the world at large outside Region I (i.e., outside the part of the world that is already committed to the automobile). At the same time, it is almost self-evident that the need for utility vehicles will increase in the developing world as it undergoes further economic growth.

It is obvious that the duration of such transitions will not only be different in the four regions, but also that some aspects of the global transition will be completed before others. For example, the design of the automobiles for the 1980s and 1990s is well underway and the first generation is already offered on all major markets. Considering that the first design phases for these automobiles were initiated more than a decade ago, we may expect that the next generation will not be on the market before the 1990s and it will be based on the current know-how. Some of these issues are considered in greater detail for Region I in the forthcoming MIT study (MIT 1982). However, only the automobile generation following this one (for the year 2000 and beyond) will bring about truly new aspects of the future automobile--aspects that are now only feasible in the "laboratory". Such innovations include new propulsion systems and fuels, perhaps automatic traffic control systems and so on. In any case, large changes in the product cannot be expected before the beginning of the next century. The time span of, say, 25 years that it might take to produce two new generations of automobiles also roughly corresponds to the lifetime of the large production facilities and to one human generation. Thus, enough time must be allowed to completely retool (robotize) and change tastes and habits for the automobile of the future. Therefore a time horizon of at least 25 years is necessary to consider fundamental changes in the product and the industry, but it could also be much greater, say up to 50 years, allowing for the completion of most of the transitions we have mentioned above.

1.6 Future Prospects

The future of the automotive industry will probably be characterized by increasing global interdependence of markets and production facilities, perhaps concentrated in the hand of a few international firms. At the same time increased flexibility in the production process could also allow smaller manufacturers to be competitive in specialized market segments. This already implies a certain conformity in the industry and its products due to the requirement of producing large numbers or very specialized cars in order to absorb large investments and research and development costs for new and changing products and production facilities. These trends can be summarized compactly as movement toward higher productivity and worldwide integration. However, while automobile production is being distributed throughout the world, it is still not clear whether the use of the automobile will spread throughout the world or remain limited to the Region I countries. One of the critical questions is whether the automobile will become the universal individual transportation system of the future or whether some alternative transport system will be implemented in Regions II, III and IV economies. No obvious candidates are in sight as yet, but some hybrid systems, consisting of already existing components are conceivable alternatives. Examples are flexible route buses or taxi services, perhaps connected with rail or air travel systems. However, even if the developing world does undergo widespread automobilization, it is not clear what kind of personal vehicle would be appropriate and successful. It is unlikely that it will be the same range of automotive products that have been successful in the industrialized countries, which are already committed to the automobile. It is more likely that the automobile for the developing countries will have to be less complex but more durable than the product offered in the industrialized countries.

Therefore, a foundational question is whether the centrally planned and developing countries (Regions II, III and IV) will skip the automobile in their future development and go directly to the next individual transport system and what role the automobile will play in such a future; if they do commit to the automobile, they will no doubt represent the largest future market, given that the industrialized market economies (Region I) are not likely to generate much more than replacement demand for automobiles.

The centrally planned economies (Region II) already have substantial automotive production capacities and growing demands. Thus, the important question in connection with Region II is not only whether they will become fully committed to the automobile as their future individual transport system, but also what kind of automotive industrial relations will exist between the centrally planned and market economies (Regions II and I). Presently, Region I exports to Region II, both automobiles and production facilities, while it imports vehicles that compete in special market segments for off-road and subcompact vehicles. It is reasonable to suppose that this exchange will intensify in the future.

Some manufacturers from Region II are already very serious competitors in the utility vehicle market. For instance, the Hungarian-made Ikarusz buses are outcompeting Western European bus manufacturers in the US. This points to a second important question associated with the future of the world automotive industry--the future of utility vehicles (trucks, buses, tractors, military vehicles and construction equipment). Certainly the demand for utility vehicles will increase in the developing world as it undergoes economic development. It is also almost self-evident that the major portion of this demand will be supplied by the domestic industry, but the know-how, production facilities and specialty components and systems will probably be required from the industrialized countries. If economic growth aspirations are to be realized in the developing world during the next 20 to 50 years, the utility vehicle market will certainly become one of the great challenges for the automotive industry.

2. A FRAMEWORK FOR THE EVOLUTION OF THE WORLD AUTOMOTIVE INDUSTRY

According to a variety of sources, including the Fiat Research Center (Businaro 1982), the world automotive industry has two basic time horizons: The "short-term", which most estimates place at around 20-50 years. Over the short term, there will be no radical changes in the industry, as the investments already made in machinery and manpower and design more-or-less determine the structure of the industry and its product, barring catastrophic events, such as wars and other natural calamities. In this short-term perspective the interesting automotive question centers upon how the radically different strategies already adopted by the manufacturers will shape the industry during the next 20 years. We sketch the basic ingredients to this problem later in the section.

The long-term horizon presents the industry in an entirely different light. Any truly radical innovation in the automotive industry in this time frame will be at the systems level, not at the level of components. The industry will witness a transition from the "styling" and "engineering" era to the "systems" era.

Basically, the potential metamorphosis the automotive industry is now facing involves a reorientation from a view of the car at a "structural" level to a view at the "functional" level. Thus, instead of designing an automobile "piece-by-piece" by trying to put together individual styling, engineering, marketing and safety designs, the new view will first consider what *functions* the car must perform and what overall constraints (e.g., pollution, safety, energy consumption, aerodynamics, etc.) it must satisfy. Then the job will be to *systematically* explore viable configurations satisfying the required functional purposes. Consequently, the industry would evolve from a "bottom-up" to a "top-down" view of its product.

Taking an evolutionary view of this process, one can view the overall situation as one of a collection of organisms (the firms) adapting to an uncertain environment (the consumers, government and nature) in order to optimize, in some sense, the organisms competitive position in the global structure we call the automotive industry. There are some obvious similarities between this automotive evolutionary view and the traditional biological view of evolution, but also a number of important differences. Since the differences are somewhat more relevant to our aims, it is worthwhile considering them in more detail:

(i) in contrast to a biological organism, the automotive industry can, to a limited degree, modify its environment by means such as political lobbying, high-pressure advertising, bribery, special discounts and so forth. However, there is always some level of environmental restriction at which the firm either adapts or goes out of business;

(ii) the "punctuated" evolution of biology appears to be absent from the industrial counterpart where we see only *incremental* adaptations. Such adaptations are usually dictated by the history of past adaptations involving knowledge acquisition and by past changes of the environment. At first glance, it may appear as if technological innovations may provide the basis for the type of discontinuous adaptations associated with punctuated evolution but, generally speaking, such technological changes come about at the component level and their degree of success often depends upon happy coincidences and fortuitous timing of independent, complementary innovations. In any case, short of a technological revolution, innovation does not usually show up as more than an incremental adaptation in the industry as a whole;

(iii) we can attempt to plan industrial adaptation, rather than just "letting it happen". That is, we can anticipate what changes will be advantageous and then actively promote those changes rather than just experimenting with random modifications;

(iv) the standard biological fitness criterion involving greater chance of offspring production is far too simplistic for the industrial setting. Multiple criteria involving profitability, protection of market niche, productivity, employment levels and so forth would be required in order to evaluate the desirability of any particular adaptive "mutation".

The evolutionary paradigm sketched above suggests that a basic question for the automobile industry over a 20-50 year horizon is

> HOW CAN THE AUTO INDUSTRY MAKE THE TRANSITION FROM A STRUCTURAL TO A FUNCTIONAL ORIENTATION AND, MORE SPECIFICALLY, HOW CAN GOOD MECHANISMS BE DEVELOPED TO EVALUATE THE "FITNESS" OF VARIOUS COMPETITIVE STRATEGIES?

The preceding considerations plainly indicate that the evolutionary metaphor is not one restricted to the automotive industry, but one which is suggestive for all industrial enterprises. However, it is important to imbed the more specific short-range automotive problems within the framework of the overall paradigm in order to integrate the two sets of issues. So we now turn to the shorter-term aspects.

It is convenient to think of the world automotive industry as consisting of three main actors playing out their roles against a backdrop of an external environment comprising four principal transition phenomena. The *actors* are: (1) the global market--the *consumers*; (2) the national governments--the *regulators*; and (3) the automobile manufacturers--the *firms*. We can then regard the ebb and flow of the world automotive trade as an exchange between the firms and the consumers mediated by the regulators. Due to economic, technological, demographic and political factors, in recent years this automotive trade has been dramatically and irreversibly affected by the following transitions: (a) the transition from national to international markets; (b) the transition from distinctly identifiable, individual products to relatively unidentifiable, homogeneous products; (c) the transition from single, national, integrated production sites to multiple, international, component production facilities; and (d) the transition from labor intensive to capital intensive production methods.

It is possible to distinguish at least three qualitatively distinct but not totally disjoint strategies that the world's automotive manufacturers have committed themselves to over the next 20 years. These are

- *The World Car Strategy*--emphasizing the integration of foreign and domestic production and a basic product range which can be modified to suit local conditions;

- *The Market Niche Strategy*--emphasizing high technology and the marketing of the same product line globally;

- *The Car as Car Strategy*--emphasizing cheap, reliable, high-quality cars with no frills or image "extras".

The actors in the complicated multi-person game we call the world automotive industry have formulated their individual strategies and actions within the environment created by the major transitions with the objective of answering the following central question:

> WHAT STRATEGY OR COMBINATION OF BASIC STRATEGIES WILL TURN OUT TO BE COMPETITIVELY STABLE AND THEREBY SHAPE THE FORM OF THE AUTOMOTIVE INDUSTRY FOR THE 21TH CENTURY?

There are many auxiliary questions of considerable importance which also must be addressed involving world automotive demand, environmental impact, resource conservation, evolution of consumer tastes, the effect of micro-computer technology and so forth. But our preliminary studies show clearly that these questions are subservient to the prime issue of overall strategic effectiveness.

For purposes of gaining an overview of the main global automotive issues, it is useful to arrange the actors and transitions in the following interaction matrix (Table 3).

The entries of the matrix can now be regarded as representing the various pieces of the mosaic which forms the background to the central questions posed earlier. Associated with each actor, transition and actor-transition interface, are major sub-issues and sub-problems which must be resolved in order to meaningfully address the overall short-term question. As an indication of the type of issues involved, consider the following list.

ACTORS

Consumers:	Competitive elimination in saturating Western market vs. transition to an emerging market in the less-developed countries
Regulators:	Environmental quality vs. economic survival of national automotive industry
Firms:	Identification and maintenance of market niche vs. low-unit costs through product homogenization

TRANSITIONS

National → International Markets:	Market expansion vs. product tailoring
Product Differentiation → Product Homogenization:	Low-unit costs vs. marketing alternatives

Table 3. Interaction Matrix of Actors and Transitions.

ACTORS	TRANSITIONS: National to International Markets	Product Differentiation to Product Homogenization	Single, National Site Production to Multiple, International Sites	Labor Intensive Production to Capital Intensive Production
CONSUMERS	Development of Automotive Infrastructure and Evolution of Consumer Tastes in Foreign Markets, especially Developing World	How to Maintain Identity in Foreign Markets at Low-Unit Costs	How to Achieve Low Costs and Avoid Local Political and Economic Constraints	Risk Involved in Automating for an Uncertain Market
REGULATORS	Level of Domestic Regulation allowing firms to be Competitive in International Markets vis-à-vis Explicit Trade Barriers	Compatibility of Regulations with Competitiveness in Diverse Markets via Product Homogeneity	Increased Employment, Productivity and Improved Balance of Payments vs. Economic Subsidies and Concessions	Employment vs. Economic Viability and Shared Development Costs + Capital Investment
FIRMS	High Investment Costs and Substantial Marketing Costs vs. Increased Sales and Decrease in Market Viariability	Low-Unit Costs vs. Product Tailoring to Submarkets	Easier Market Penetration and Economic Concessions (incl. joint ventures) vs. Centralization and Less Expensive Final Assembly	Lower-Unit Costs vs. High Capital Investment and Increased Minimal Production Lots

Single, National Production Site → Multiple, International Sites:	Distribution, cultural and management problems vs. tariff and regulatory circumvention and economies of scale
Labor Intensive → Capital Intensive Production:	Automation vs. unemployment and labor relation problems

As noted earlier, the short-term transition phase is estimated at around 20 years. The issues confronting the automotive industry during this time involve the mutual interrelationships and interactions between the markets, governments and manufacturers. Each of these components must formulate its transition strategies against the background of several natural fluctuations and trends involving economic, demographic, political and technological factors, as well as against the background provided by the other main actors. It is the existence and nature of mutually compatible transition strategies that comprises our view of what constitutes the core of the short-term problem facing the automotive industry today.

It is clear from this discussion that any real understanding of the basic short-term question will involve an interdisciplinary effort and will require examination of the industry from several vantage points, as emphasized, for instance, in the multiple-perspective view outline in (Linstone 1981).

The long-term problem of the industry involves the possibility of the paradigm shift from a structural to a functionl orientation. In this context, the problem is of an evolutionary nature similar in some ways to a biological process, but with significant differences. Identification of a suitable framework for viewing this evolutionary process is a question of genuine scientific interest, quite independent of the particular form taken in the automotive industry. Light shed on this question will illuminate and unify a wide spectrum of issues in organizational theory, industrial management and strategic planning.

3. CONCLUSIONS AND A PROSPECTUS FOR FUTURE RESEARCH

The preceding sections have outlined some of the important issues that will shape the development of the world automotive industry over the coming 20-50 years. In addition, a framework of an evolutionary nature has been suggested as an appropriate vehicle upon which to base a system-analytic study of many of these important issues. In order to put into perspective our suggested research plan, which is aimed at developing a perspective from which to project the industry into the 21st century, it is useful to examine briefly two other recent studies of the world automotive structure, those carried out by the MIT group and by the EEC.

- *MIT Study*. This study focuses upon the problems of the automotive industry over the next 20 years as seen by high-level managers and designers. The structure of the study is such that its primary emphasis is upon providing a forum for managers and decisionmakers from the automotive industry of the industrialized world to meet periodically for discussion of common questions and to project the future of various aspects of the industry such as demand, technological developments, production and so forth. While the final study report has not yet been issued, preliminary versions indicate no actual modeling efforts form a part of the MIT study and so, in the conventional sense, one cannot label this as an "analytic" view of the automotive industry's future evolution;

- *EEC Study*. This investigation was divided into two quite distinct parts: the future of the Western European automotive components industry and the future structure of the employment patterns in the automotive firms up to the year 2000. The primary thrust of the EEC study was to examine issues such as job mobility, the competitive position of the component manufacturers vis-à-vis Japanese competition, future patterns of labor relations in the automotive firms and so on. In short, this study emphasizes immediate ($\leq$15 years) industrial adjustment aspects of the automotive industry as they relate to the Western European countries.

As far as could be determined, the MIT and EEC studies are the only studies available, at least in the open literature, which look at the automotive industry as a whole and which emphasize its international nature.

From the standpoint of the arguments presented earlier, there are several serious gaps in the MIT and EEC studies which must be filled before any real understanding of the industry's future can begin to emerge.

(i) *time horizon*--most of the substudies comprising the MIT and EEC reports involve a time horizon of no greater than 20 years. Since the path of the industry is *fixed*, more-or-less, for this period by past decisions and capital investments, the only real opportunity for significant restructuring of the industry is in the period *beyond* the next 20 years. Thus, if one wants to explore how the industry may look in the 21st century, it is necessary to look beyond a 20-year horizon; except for minor variations, the basic future for any shorter period has already been programmed;

(ii) *global aspects*--the MIT and EEC studies are multinational, but only to the extent of including the automotive industries of North America, Western Europe and Japan (Region I above). This is not enough. The real future of the world automotive industry is going to be determined not just by what happens in Region I, but by the decisions and developments in Eastern Europe and the developing nations (Regions II, III and IV above). As has already been noted in Section 1, questions involving whether or not the developing nations will bypass the automotive stage and go directly to the next stage of mass transportation or what kind of tie-in Eastern European manufacturers will make with Region I firms are absolutely crucial to an understanding of how the automotive industry will reshape itself in the 21st century.

(iii) *utility vehicles*--none of the studies yet carried out have included the influence of demand for utility vehicles (trucks, buses, tractors, military vehicles and construction equipment) in their analyses. This omission is particularly important in relation to the previous point regarding developing countries since the demand for such vehicles in Regions II-IV is *certain*, in contrast to Region I, where there is only a replacement market and in contrast to passenger vehicles whose demand will wax and wane with consumer tastes and economic fluctuations. Thus, the omission of utility vehicle considerations seriously biases any projections about the long-term structure of the industry.

Other omissions in the MIT and EEC studies could also be cited (e.g., lack of integration of the automotive sector with cultural and demographic trends, links to the energy and raw materials sectors, etc.) but, in our view, the ones cited here are the most serious, and provide the greatest obstacles to a balanced view of how the industry may evolve over the next few generations.

RESEARCH PROSPECTUS

Putting the above observations together with the background material of Section 1 and the conceptual framework of Section 2, an outline begins to emerge for a research program directed at uncovering alternative futures for the automobile industry in its evolution into the first half of the next century. While it is wildly premature to speculate on the specific details of such a multi-year, multi-man program without much more exploratory effort, the general components are relatively clear. The basic steps are:

Step 1. Extreme-Case Extrapolations. In order to establish some realistic boundary conditions for *any* study, it is necessary to examine limits on production capacity, consumer demand, technological advancements, energy supply and so forth. These limits must be established against a background of political, economic, cultural and environmental constraints. While some tentative projections, or better speculations, have been published about future demand, there have been no studies aimed at other equally important factors such as raw materials supplies, production capacity and so on and certainly no projections over the time frame we suggest. The results of the extreme-case analyses can then be employed in

Step 2. Scenario Construction. Since we don't know what the world will be like 50 years from now and desparately want to do some analysis, it will be necessary to invent various worlds to analyze. This means a variety of scenarios need to be constructed, constrained by the investigations and analyses of Step 1. Each scenario generates a different world which can be studied using the formal structures developed in

Step 3. Paradigmatic Development. In order to study the implications of the various scenarios of Step 2, it will be required to formulate mathematical models based upon some underlying developmental paradigm. In Section 2, a paradigm loosely structured around an evolutionary theme is suggested, but alternatives must also be examined. For instance, a *structuralist* paradigm founded upon the ideas of wholeness, transformation and self-regulation may prove viable. In any case, the basic components of each candidate paradigm must ge given a mathematical representation if the dynamical consequences of the scenarios are to be explored both qualitatively and quantitatively. Following identification of appropriate paradigms, the final stage of the program can be initiated.

Step 4. Integration of Macro-Level Components. The preceding steps have all regarded the world automotive industry as an object connected to the external world only through a link called "the environment". The final stage of the projected research program is to make this link more explicit and to incorporate specific external factors into the basic models. In this connection, it is anticipated that explicit subsystems representing cultural/demographic issues, energy availability, new materials supply, global economic conditions and so forth will be adjoined to the central automotive industry models.

In summary, then, our conclusion is that the development of the world automotive industry over the next 50 years can and should be investigated using the systems-analytic framework outlined above. Notwithstanding the excellent studies of the industry as exemplified by the MIT and EEC groups, there has as yet been no truly global, long-term view taken of the automotive industry and it is our strong feeling that the most accessible route to a view of what the industry will look like in the 21st century is through a systematic research program structured along the lines indicated above.

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