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Industrial development of car disassembly - ergonomics and system performance

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Car disassembly and ergonomics in Sweden: current situation and future perspectives in light of new environmental legislation

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Due to external environmental concern a new European Union (EU) legislation is now increasing the demands on car recycling. The aim of this paper is to present the ergonomics of today's disassembly production systems as well as initiatives and expectations about future systems. This is to provide a basis for development of production systems according to both productivity and workers' musculoskeletal health. Explorative methodologies were utilized. The following results were found: (1) car disassembly today includes two main tasks: dismantling of components to meet environmental demands and dismantling of valuable parts. The latter allows for good business economics for all the investigated companies; (2) performance demands are in general low and resemble a craft-type production, i.e. the work comprises a rich variety of tasks and low time pressure; (3) musculoskeletal disorders seem not to be a significant issue; (4) design for disassembly/recycling is not a significant issue in the manufacturing industry today. Accordingly, communication between dismantlers and design engineers is sporadic. However, in a long-term perspective, the key stakeholders consider such interaction important to obtain more efficient disassembly systems. Due to the EU legislation more non-commercial parts of the car must be disassembled in the future. Thus, rationalization of disassembly systems is anticipated and possible ergonomic implications are discussed.

1. Introduction

Car dismantling is one of the oldest fields of recycling in Sweden. Some companies have been in business since 1920 (http://www.sbrservice.se). In the year 2000 there were more than 700 authorized car dismantlers in Sweden of which approximately 300 dismantled about 80% of all cars that were scrapped annually. Each company employs 3–20 workers and dismantles 400–2000 cars a year (http://www.sbrservice.se).

Recycling is an important part of a sustainable society. Residents of the industrialized countries comprise only about 20% of the global population; however they consume about 80% of natural resources (Ennals 2001). In order to obtain decent living standards for the remaining 80% of the global population we need to reduce material consumption in industrial countries. This reduction may be obtained by more wide-scale reuse and recycling of products (Realff *et al.* 2000).

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A new EU directive on used vehicles has recently been introduced (Directive 2000/53/EU). The directive is motivated by a concern for the external environment and it demands that 85% of every scrapped car by weight should be recycled by 2006 and 95% by 2015. About 15 million passenger cars were sold in Europe in the year 2001 (http://www.acea.be/ACEA/ auto_data.html). All of these cars will need to be scrapped one day. According to the Swedish Car Recyclers' Association (SBR), approximately 300 000 passenger cars were scrapped in Sweden in 2001 (http://www.sbrservice.se). In this country about 80% of each car was recycled (year 2001). Due to present national legislative demands the following parts and materials with low or no market value need to be dismantled or separated: fuel, anti-freeze, oils, oil filters, brake-liquids, start batteries, balance weights on tire rims, air conditioning, air bags and belt stretchers, mercury circuit-breakers, radioactive material, catalysts, tires. Profits in this industry are mainly obtained from parts disassembled from newer, crashed cars (so called 'insurance cars'). As Sweden is one of the leading countries in the area of car dismantling and recycling, national legislation already demands 85% recycling from April 2002 (Miljödepartementet 1997). Accordingly, glass should now also be dismantled from the cars. The increased dismantling and recycling of car parts essentially without market value is anticipated to cause a greater demand for rationalization of the production systems for disassembly. From year 2006 producer responsibility will come into effect. The impact of this on key stakeholders' attitudes regarding Design for Disassembly (DFD)/Recycling (DFR) needs to be investigated.

The car manufacturing industry ('forward factories') has focused its R&D on effectiveness and the work environment ever since Taylor's ideas were realized by Henry Ford at the beginning of the 20th century (e.g. Berggren 1992, Björkman 1996, Engström *et al.* 1996, Kadefors *et al.* 1996). Part of the research has focused on ergonomic issues due to musculoskeletal health problems experienced by workers in the car assembly industry (Landsbergis *et al.* 1999, Fredriksson *et al.* 2001). These problems were possibly a consequence of production system rationalizations. Thus, lean production and total quality management (TQM) have been claimed to contribute to poor ergonomics and cause musculoskeletal disorders (Berggren 1992, Vahtera *et al.* 1997, Landsbergis *et al.* 1999) while others have claimed the opposite (Womack *et al.* 1990).

The anticipated rationalization of the car dismantling industry will create an opportunity for ergonomics R&D to act proactively within this process. By collecting appropriate information it may be possible to balance efficiency and ergonomics in the development of future production systems. With this background it is the aim of this paper to document statements obtained from key stakeholders on the present and future production and ergonomic issues affecting the car disassembly industry. This information may then be used to build 'recycling scenarios' with a focus on ergonomics in future 'backtrack factories'. Special attention is given to issues related to physical risk factors for occupational musculoskeletal health. The paper investigates: (1) the present ergonomic conditions as perceived by a representative sample of Swedish car dismantling companies; (2) dismantlers' perceptions, attitudes and viewpoints about disassembly production systems and DFD/DFR issues; (3) attitudes, initiatives and expectations regarding the dismantling industry among authority stakeholders as well as design engineers from a Swedish car manufacturing company.

2. Material and methods

2.1. *Study design*

Explorative methodologies were utilized, comprising site visits, document/literature survey and semi-structured, in-depth interviews with representatives of key stakeholders (Miles and Huberman 1994).

Three groups of stakeholders were interviewed: (1) dismantlers; (2) design engineers and 'environmental representatives' from the Interior and Climate Engineering department of a major car producer in Sweden ('car seat' group); and (3) representatives of government and independent policy makers, branch organizations for the car manufacturing and disintegration industries. More details are provided in table 1.

The interviews were supplemented by a one day workshop focusing on DFD/DFR issues of car seats. Participants included three representatives from the car dismantling industry, three from car manufacturing industry (including a design engineer and a 'recycling representative' from customer service) and five researchers.

The site visits included seven car disassembly facilities, a car shredding plant, and the design and engineering departments of a car manufacturer.

The survey of literature and documents complemented and validated parts of the information provided by key informants. Furthermore, it identified aims, missions and policies of organizations, regulatory demands, national and international standards of relevance for this study, and companies with attempted solutions to problems.

Selection of respondents from the dismantling industry was initiated via an Internet search of the Swedish Car Recyclers' Association (http://www.sbrservice.se). The companies were chosen based on information provided about their size, productivity as well as the number of years they had been in business, and with a geographical preference of proximity to the researchers' site. Out of 47 contacted companies, 17 expressed an interest in the study. The first 13 companies that responded were chosen for the interviews.

Car design engineers and authority stakeholders were chosen based on their job responsibilities and experience. Information about potential interviewees was obtained through initially established contacts.

2.2. *Conceptualization of ergonomics in a production system perspective*

Physical risk factors for musculoskeletal disorders are usually expressed in terms such as posture, force and repetition (Bernard 1997). At the operator level these factors depend on characteristics in the production system according to applied production strategy, that is technology level and work organization (Winkel and Westgaard 1996). Based on this, a conceptual framework has been developed describing the chain of events that can lead to work-related musculoskeletal disorders (Westgaard and Winkel 1997, Mathiassen and Winkel 2000, Neumann *et al.* 2002). The technology level may be defined as the distribution of work tasks between machines and employees, and the work organization as the distribution of work tasks between the employees (Winkel and Westgaard 1996). Thus, both factors may reflect critical issues in terms of ergonomics/musculoskeletal risk factors.

2.3. *Qualitative interviews*

The qualitative interviews gathered information of ergonomic relevance in relation to the two main themes: production systems for disassembly and DFD/DFR. Table 2 presents the main thematic items covered during the interviews.

Interviewees	Number	Years in the job/ experience (range)	Responsibility
Car dismantlers	13	(from year 1968 to 1994)	Chief managers with practical experience of car dismantling
Recycling representative; customer service	1	10	After market issues, dismantling handbook (International Dismantling Information System), Design for Recycling
Design engineer	1	13	Setting of requirements; service, testing with car seats
Design engineer (environmental coordinator and eco-engineer within Interior & climate engineering)	1	2	Communication of demands to constructors and suppliers; setting up long-term development goals
Principal design Engineer	1	18	Quality relay, warranty, reliability forecast, front and rear seats
Designer	1	3	Process quality; working with quality environmental questions in product design
Representative of Swedish Environmental Protection Agency from the branch of car scrap	1	7	Introduction of regulations, or general council, meeting with car branches
President of Car Recyclers Association	1	11	Representative of car dismantlers working with certification systems for car disassembly facilities, promoting of development in car dismantling trade; recycling and parts recovery issues
Technical consultant of a major shredding plant	1	20	Working with projects related to car shredding; projects on development of new techniques in shredding
President of car manufacturers organization	1	in Bil Producent Ansvar Sverige AB – 5–6 yrs	Working with producer responsibility and car recycling questions; support for car manufacturers and importers in Sweden regarding these issues

Table 1. Basic information about interviewees.

Interview guides were constructed to ensure that all topics considered relevant for the study were covered. Their contents varied according to the targeted group of stakeholders. Interviews with car dismantlers covered incentives to work; productivity/requirements concerned the number of disassembled cars per year, whether there

Dismantlers
Present situation
Personal information
Factual information about the company
Incentives for the work
Productivity/requirements
Disassembly production systems: inflow, operations, outflow
Limitations to recycling
Work content/perceived problems today
Suggestions to alleviate ergonomics problems in disassembly
Future challenges and expectations
Influence of legislation on disassembly production systems and their work content
Designers/constructors
Present situation
Personal information
Requirements and determinants for design
Limitations and facilitators to DFD/DFR
Future challenges
Impact of legislation on producer responsibility
Authority stakeholders
General information: personal info, responsibilities in relation to disintegration/disassembly
Present situation
Organization of disassembly systems: size, organization
Future situation
Organization of disassembly production systems
Likely scenarios for the future
Impact of legislation on disassembly work

Table 2. Main thematic items of the interview guide, in the order they were usually taken up during the interview.

were any requirements for this number and, as a follow-up, whether the company had contracts with manufacturers. Present disassembly production systems and ergonomics were also covered. The researcher introduced some examples of ergonomics problems (e.g. repetitive work, heavy loads) prior to the question about perceived problems today. Furthermore, questions concerning future expectations and challenges with regard to production systems for disassembly were also posed. All comments of potential relevance for the occupational musculoskeletal health of workers were noted. Other issues of ergonomic significance, such as quality of products and social support of workers, were considered through several of the thematic items in the guide (table 2).

The interviews of car design engineers mainly aimed to identify factors in car design that would make disassembly and recycling easier. Main themes emphasized disassembly in design, facilitators and barriers to design for disassembly, impact of legislation on producer responsibility and viewpoints on specific ergonomic solutions to disassembly problems. For some questions the design engineers were asked to prioritize criteria in the design of car parts. Eight criteria were presented but additional ones were allowed to be included.

The interviews of authority stakeholders and representatives of the industrial organizations aimed to get an overview of the car disintegration industry today. All respondents were asked to express their views about future production systems for dismantling and alternative scenarios in this respect.

The interviews (in Swedish or English) were tape-recorded and took place at the respondents' workplace at a time chosen by them. Each interview lasted 1–2 h. The questions from the relevant interview guide were posed in the order listed in the guide. However, if a theme and questions were covered out of order the interview was allowed to continue along this vein without repetition later. The interviews were generally conducted in a manner that resembled an open, relaxed conversation.

2.4. *Analysis of interviews*

All tape-recorded interviews were transcribed to text files. The interview material was first read to identify the key issues. Questions and topics from a semi-structured interview guide served as an initial organizing framework. Data was arranged according to the responses to each question or topical area generated by the interviewer (Sandelowski 1995). Coding was performed by analyzing whole paragraphs. Names were assigned according to the themes from the interview guides as shown below (Strauss and Corbin 1998).

The answers were extracted from the written transcripts of the interviews, for each person separately. Afterwards the answers from all interviewees were grouped together in secondary files for the following issues from each of the three interview guides.

2.4.1. *Dismantlers*

- Present situation
  - Incentives for the business, demands from society, limitations to dismantling
  - Suggestions to alleviate ergonomics problems in disassembly today
- Future
  - Expectations regarding production systems and challenges regarding disassembly work

2.4.2. *Design engineers*

- Present situation
  - Situation with regard to disassembly/recycling in design; facilitators and barriers in design
  - Suggestions to alleviate ergonomics problems in disassembly
- Future challenges with regard to DFD/DFR

2.4.3. *Authority stakeholders*

- Present situation with regard to car dismantling systems
- Future organization of production systems for disassembly (expectations and challenges)

To answer our research questions, the final grouping of the above issues from the respondents was organized into two themes:

1. Disassembly production systems
2. DFD/DFR

Each theme focused on the perception of present problems and experience-based suggestions for future solutions.

Citations from the interviews in Swedish are translated into English.

2.5. *Validity of data*

The respondents were chosen on the basis of their experience and knowledge of topic areas (see table 1). Furthermore, data was validated by triangulation (Mays and Pope 2000), for instance by crosschecking with documents and Internet information. The authority stakeholders were asked to describe the present organization of car disassembly systems, to check convergence to the dismantlers' descriptions. The site visits provided a further opportunity for triangulation.

2.6. *Workshop*

A one day workshop on DFD/DFR was organized. The specific aim was to investigate key stakeholders' attitudes, viewpoints and ideas regarding DFD/DFR when they were brought together for a full working day. The workshop was organized and sponsored by the manufacturer without any external financial support. Car seating was chosen as the topic, as the average weight of car seats has increased 2–3 times during recent decades, thus increasing the need for DFD/DFR initiatives. The communication process between the stakeholders during the workshop was facilitated by use of a previously developed method (Bark 1995). The workshop was evaluated by a questionnaire distributed to the participants at the end of the day. The workshop was evaluated using the following questions: whether the aims of the workshop (1) to facilitate recycling of car seats and (2) to test whether this method could facilitate easier and more effective recycling of car parts, were achieved, (3) whether the communication between dismantlers and design engineers worked, (4) whether group composition and (5) size were the most appropriate in relation to the aim of the workshop.

The responses to the questions were scored on a five-point ordinal rating scale. The participants were also encouraged to write down additional viewpoints on the workshop, as well as other actions needed to increase co-operation between dismantlers and design engineers including frequency of meetings necessary to optimise co-operation.

3. Results

3.1. *Production systems*

3.1.1. *Present situation (year 2001)*

Disassembly includes two main tasks: dismantling of the components which should be removed from the cars due to environmental demands (cf. Introduction) and dismantling of valuable parts according to customer demands. The tasks today are performed, in general, as during previous decades. The total working time per car is between 8–16 h: most of which is spent removing parts of commercial value to be sold later at a profit. The disassembly of non-profit parts takes approximately one hour, implying only modest physical exposures.

Work demands are mainly set by the Swedish Car Recyclers' Association (SBR) and Car Manufacturers' Association which both have their own certification system. Those certified by the Car Manufacturers' Association, for example, are obliged to report every three months the number of stored and disassembled cars and the amounts of any sold parts. The Swedish Environmental Protection Agency demands these documents as well.

Three companies were ISO9002 and 14001 certified and three were preparing for this certification.

The majority of cars disassembled in the interviewed companies appeared to be 'insurance cars'.

All the investigated companies mentioned good economics in the business. As expressed by one dismantler: 'We still have a big or good gross earning here so there is very good margin on what we do . . .'.

Today disassembly facilities resemble car repair workshops, where set-up time is considerable and a rich variety of tasks are performed (as seen in figure 1(a) and 1(b)).

This contributes significantly to the modest physical exposures perceived by the dismantlers. The following quotes illustrate this:

> Now there is a lot of set up time: you place the car on the lift, lift it up, disassemble it part by part and then it goes down and out.

> By 'disassembly' I aim not only at disassembly but also that information needs to be administrated, and it needs to be updated, checked, and a lot of numbers need to be written down referring to the components . . . thus people do not just use the screwdriver for 8 hours.

The mechanization of disassembly today includes primarily lifting tools, overhead cranes, pneumatic tools, electric saws and forklifts (see figure 1). However, the respondents claimed a need for special tool development for disassembly.

None of the dismantlers considered occupational musculoskeletal problems/ergonomics as a significant problem today. As expressed by one dismantler: '. . . now there is a job with a lot of variety and moving around a lot and doing different things which is good for the body . . .'.

When questioned, ergonomics problems were expressed as:

> It may be somewhat monotonous . . . some parts need to be disassembled from all cars . . . thus it is repetitive all the time.

> . . . vibrations . . . from air powered tools.

> When working under the car . . . this is heavy work.

> . . . when the car is produced, it is produced in a way that is easy and good for the human with a lot of mechanical help. Now we have to disassemble everything by hand and the only thing that we can do is to put a car up and down on lift . . . you have to work under the car, it's very hard . . . the position of your arm and the way you work.

Other mentioned problems concerned old scrap cars' rusted condition; broken components (e.g. glass), gasoline fumes and dirt. The dismantlers claimed they did not consider time pressure a significant issue. This was supported by impressions from the authors' site visits.

(a)

(b)

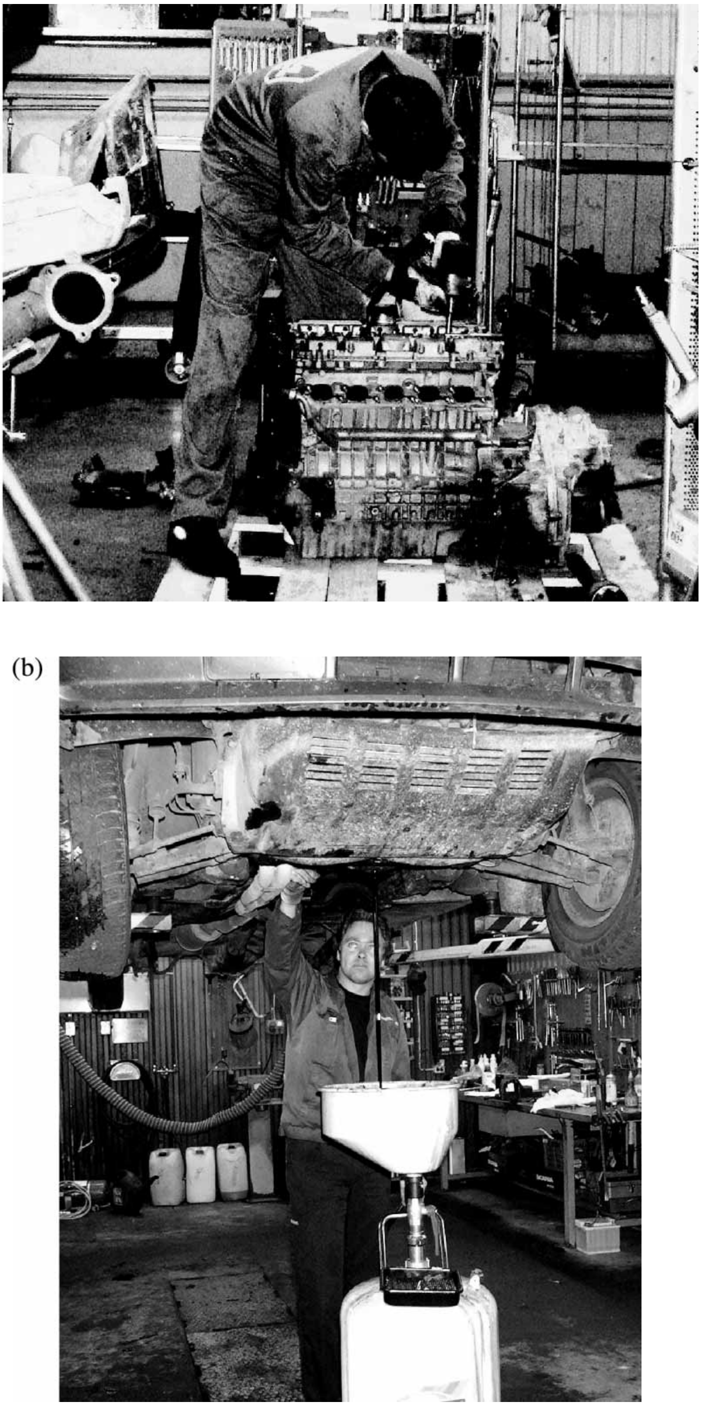

Figure 1. Disassembly of parts from a car engine: (a) unscrewing parts, (b) removing oil. Although poor working postures occurred, the duration generally seemed to be short.

3.1.2. *Expectations regarding future production systems and ergonomics*

One of the dismantlers described the current situation as follows:

> Mainly it is a very old business ... which works like it did in the 20s and the 30s when it started, and it is going through almost a revolutionary process at the moment.

It was anticipated by the dismantlers that the amount of non-profit work per car would increase in the future.

To comply with the legislative demands on recycling, the respondents emphasized that parts/materials without present market value also need to be disassembled from cars in the future. These include: glass/windows, plastics/interior and cables. Interviewees indicated the need to create a value for these items. In particular, all authority stakeholders indicated that the main challenge for the car producers is to create a market for used car parts.

The dismantlers had only a few viewpoints regarding future disassembly systems. Two owners of relatively large businesses mentioned rationalization of the disassembly production system and had investment plans for new disassembly lines for end-of-life vehicles (ELVs). One dismantler expected that jobs in such new systems would have inferior ergonomic qualities:

> These new tasks are monotonous, dangerous and not ergonomically sound [from the workshop].
>
> Since they [workers] are going to do the same thing the whole day, we also put a pressure on them ... we are going to have 1 or 2 men who only take off wheels, the whole day through ... they will have a lot more stress.

The authority stakeholders offered more specific views and expectations regarding future disassembly systems compared to dismantlers. All four mentioned a future transformation of the dismantling industry. They stated that the initial challenge for car disassembly plants is to fulfil the requirements for authorization and thereby be certified by July 2002 (new certification demands from Swedish Environmental Protection Agency from this date). All of them pointed out the need for co-operation between car dismantling and car manufacturing industries to facilitate the future organization of the disassembly industry. They expected that the number of authorized disassembly companies will be reduced, from today's 600–700 to about 100–150, each one dismantling approximately 2000 cars/year. This reduction was expected due to legislative requirements as well as environmental, economical and competitive demands. These plants would disassemble cars for spare parts and all liquids. In addition, new 'regional plants' for ELVs were anticipated to emerge, performing rational material dismantling of 8000–9000 cars/year on a line-type system.

One of the possible scenarios mentioned by the president of the car recyclers organization, was that ELV factories would develop into a co-operative of 5–6 disassembly plants in the densely built-up areas in Sweden. Two authority stakeholders considered that the new systems might result in impaired ergonomics: 'Mechanized rational line system may lead to greater time pressure.'

One stakeholder described a scenario with regard to future jobs in disassembly production systems concerning specialization within ELV factories; one job type would be glass dismantling. A potential ergonomic improvement through job rotation was mentioned by another authority stakeholder. It was emphasized that future jobs would require increased knowledge and competence among dismantlers, especially in systems for dismantling valuable parts.

A closer relation between car manufacturers and dismantlers was anticipated and a scenario was mentioned where disassembly facilities (especially in more population dense regions of Sweden) might dismantle only one specific car brand.

All authority stakeholders anticipated that more levels in the disintegration industry would be created corresponding to the different tiers at the manufacturing side. For example, a manufacturer of air bags and safety systems may build a facility of its own for deploying air bags. Moreover, dismantlers may disassemble electronics units from the cars and send them to a specialized facility for further treatment. In the longer perspective expectations focused on the shredding industry, which would have to improve their facilities in order to obtain a higher level of recycling through energy recovery. It was hypothesized that if a shredding facility had the technology to separate fractions of a car for material recycling then disassemblers could remove only valuable parts and send the rest to that facility. However, such technology has not yet been developed.

3.2. *Design for disassembly*

3.2.1. *Present (year 2001)*

Design for disassembly is a relatively new approach to design. Cars have been constructed to be 'repairable' and thus can be disassembled to some extent. There was no recycling department within the investigated car manufacturer. However, there was a recycling/disassembly representative who worked in the 'after market'/customer service division. The investigated manufacturer had no guidelines for DFD/DFR. When asked about the knowledge regarding disassembly work, only the recycling representative (out of the five respondents) expressed awareness of dismantlers' work. The interviewed design engineers stated a lack of familiarity with this issue. However, according to the principal design engineer 'some colleagues had visited a dismantling facility'. There was no formalized communication between dismantlers and design engineers today. As stated by the recycling representative, he is a 'link' between dismantlers and design engineers.

Table 3 presents determinants/criteria for design that were ranked by design engineers. The table illustrates different competing concerns in design/product development. It was observed that many of the respondents prioritized the concerns according to their job responsibilities, that is the environmental co-ordinator ranked the environment first. However, the recycling representative allocated the highest rank to manufacturing/assembly as 'easy manufacturing leads to better, under present circumstances, economy'; disassembly came second. All five respondents indicated internal company guidelines for design as important criteria. These guidelines, in turn, reflect external requirements, regulations and directives. One respondent also mentioned customer demands and competitor companies as significant concerns.

Perceived barriers and facilitators to design for disassembly/recycling are presented in table 4. All but one respondent pointed out business economics as the main barrier to DFD/DFR. Another important barrier perceived was insufficient information feedback from engineering to the recycling representative and vice versa. Similarly, the design engineers mentioned lack of communication between different departments within the manufacturing company. Regulations for DFD/DFR would act as a facilitator as confirmed by the environmental co-ordinator, principal design

Environmental coordinator	Designer	Design engineer	Principal Design Engineer	Recycling representative
1. Environment	1. Aesthetics/design	1. Safety	1. Solidity/quality	1. Manufacturing
2. Disassembly	2. Functionality	2. User ergonomics	2. Reliability	2. Disassembly
3. Recycling	3. User comfort/ ergonomics	3. Aesthetics	3. Safety	3. Safety
4. Other: low weight	4. Manufacturing/ assembly	4. Disassembly = service	4. Economics	4. Quality
5. Safety	5. Economics	5. Functionality	5. Service including disassembly	5. Comfort
6. Functionality	6. Safety	6. Comfort	6. Recycling	6. Functionality
7. Economics	7. Recycling	7. Manufacturing	7. Manufacturing	7. Recycling
8. User comfort	8. Disassembly	8. Recycling (but is included in disassembly)		8. Economics
9. Aesthetics				9. Aesthetics
10. Manufacturing/ assembly				
		Above all economics		

Table 3. The interviewees' ranking of determinants for design.

List of barriers (B) and facilitators (F)	Environmental coordinator	Designer	Design engineer	Principal design engineer	Recycling representative
Economics	B	B		B	B
Regulations[a]	B	F	B	F	F
Materials[b]	B	B	B	B	B
Environment	F	F			F
Organization within manufacturer	B	B	F[d]	F	B
Lack of knowledge	B	B			B
Guidelines	F	F		B	
Culture in the company	B	F	F	B	B
Information feedback[c]	Not sufficient today	B	F	B	B
Market	B	F		B	

Notes:
[a]Regulations – where 'B' = there are no regulations for DFD/DFR; if they existed – the response would be 'F' (as mentioned already by some).
[b]Materials – presently they are mixed – therefore response 'B'; otherwise response would be 'F'.
[c]Info feedback – it would be 'F' however presently there is insufficient or no feedback.
[d]'however it is hard to work with design department'.

Table 4. Present barriers (B) and facilitators (F) to the design for disassembly/recycling, with some future implications.

engineer and the recycling representative. As stated by one of them:

> There may be one sentence in our internal instructions indicating that it has to be easy to disassemble ... but time demands should also be included ... this should be included in our engineering documents.

That is, there is a need for a quantitative formulation of this requirement to ensure an effect.

Finally, culture and attitudes at the manufacturing site were seen as both barriers and facilitators to the design for disassembly.

3.2.2. *Future DFD/DFR*

From the year 2006 car manufacturers are financially responsible for all 'end of life' vehicles (recycling) on the market.

Table 5 shows disassembly problems, which need to be solved in the future, according to the car disassemblers. They indicated two main hindrances to the increase of disassembly/recycling: (1) inappropriate DFD/DFR; and (2) lack of market/no value of the parts. If the components take too long to disassemble, they remain in the car and are shredded. As mentioned by one dismantler:

> If there is an aluminium strip that takes half an hour to dismantle, we leave it there; it should not take more than a minute to take it out, it has to be really fast, otherwise there is no point.

The respondents gave, however, some practical ergonomics solutions for DFD/DFR:

- design-related, for example:
  quick-release-fixation in bumpers, easy hook-device to fix seats in the floor
  standardization of parts
  zipper around seat material

Time consuming ($n = 12$)	Lack of acceptable solutions ($n = 3$)	No value ($n = 11$)	Lack of knowledge ($n = 2$)
Glass/windows	Glass/windows	Glass/windows	
Cables	Cables	Cables	Cables
Air bags/safety system	Air bags/safety system	Car seats	Air bags
Car seats		Plastics	
Plastics/interior materials			

Table 5. Disassembly problems in relation to car parts/materials that need to be solved in the future.

- related to closer cooperation with manufacturers:
  it would be good to perform some trial-disassembly before they produce 10 000 cars
  establishment of *help-desk for dismantlers*
  updated manuals for disassembly from manufacturers

The design engineers had similar to dismantlers suggestions concerning specific ergonomics solutions for DFD/DFR, for example fastening devices such as clips or other fixation elements for outer materials (to separate seat material from foam). Thus, it was suggested to combine only matching materials, especially in the case of plastics and to label all kinds of plastics for easier recognition and separation. One design engineer mentioned efforts to label all the plastics, not only those according to the manufacturer's requirements above 50 g. There were solutions related to the standardization of components of seats such as back panel and metal frames in which seats are placed, for different cars within a vehicle brand group.

All dismantlers admitted lack of knowledge relating to expected future disassembly demands. This was expressed in two different ways. Two respondents communicated a deficiency of knowledge concerning specific parts (cf. table 5), while 11 respondents mentioned as a future challenge a general increase in competence and knowledge in order to disassemble more complex cars. This was also acknowledged by the authority stakeholders.

Design engineers stated that the main challenges in the future would be to increase their knowledge of DFD/DFR and to co-operate with different groups engaged in design and product development on the manufacturer side (see barriers in table 4). The principal design engineer made the point with this comment: 'We have some ideas about service and disassembly but according to the service department we don't do that'.

Finally, a need for co-operation between dismantlers and car manufacturers (design engineers) was brought up in the interviews as a solution to future ergonomics problems in disassembly.

3.3. *Communication trial: the workshop*

The workshop can be viewed as an extension of the interviews and a communication experiment between the major stakeholders.

The results of the questionnaire assessment of the workshop showed that the aim to facilitate recycling of car seats was achieved (4.5 on a scale of 1 (not at all) to 5 (yes, absolutely)). The other aim, to test whether this method could facilitate easier and more effective recycling of car parts, was also achieved (rank 4). Communication between dismantlers and design engineers worked successfully (rank 5). The group composition was appropriate in relation to the aim of the workshop (rank 4). The group size was just right (rank 2 on a scale of 1 (too small) to 3 (too big)).

The outcomes of the workshop demonstrated that in the short term, there is a need to identify and develop methods and/or tools to facilitate recycling of the existing products of present and past car generations, e.g. for the dismantling of glass and windshields, and disassembly of back panels and cushions from the seats. Figure 2 shows two different solutions for separation of upholstery (cushions) from the back support in the car seat; figure 2(a) presents an easier solution from an older car, figure 2(b) from a new car model.

Furthermore, the development of handling and lifting tools for easier removal of car seats is needed. In the long run, initiatives should be taken to study both positive and negative consequences of an increased level of recycling of existing products in terms of physical workload. The group wanted continued workshop meetings 1–2 times per year as well as establishing a network of design engineers and dismantlers via their branch representatives. The principal design engineer also

(a)

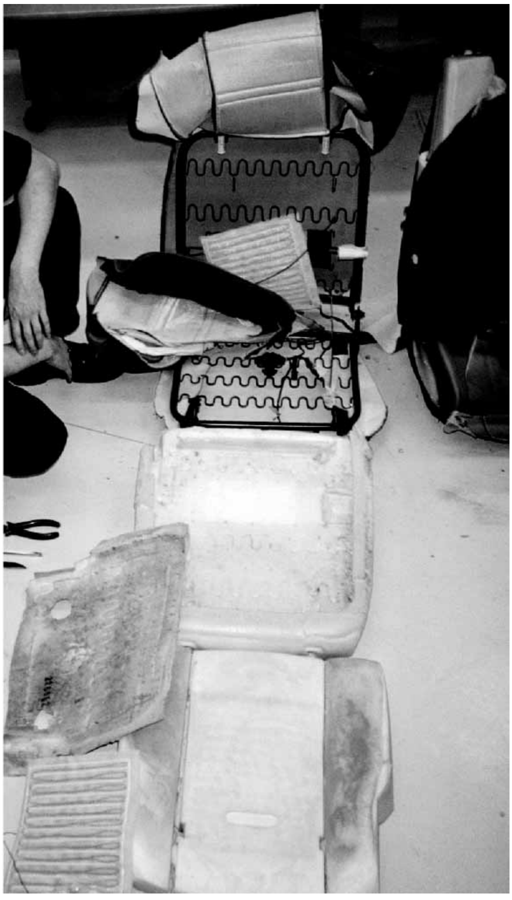

Figure 2. Car seats: (a) simple old seat (1996); seat foam not integrated in the frame; zipper to remove the outer material without cutting; no electric devices; (b) complex newer seat (produced today); *to the left*: back panel embedded in the seat frame, *to the right*: numerous electric components.

(b)

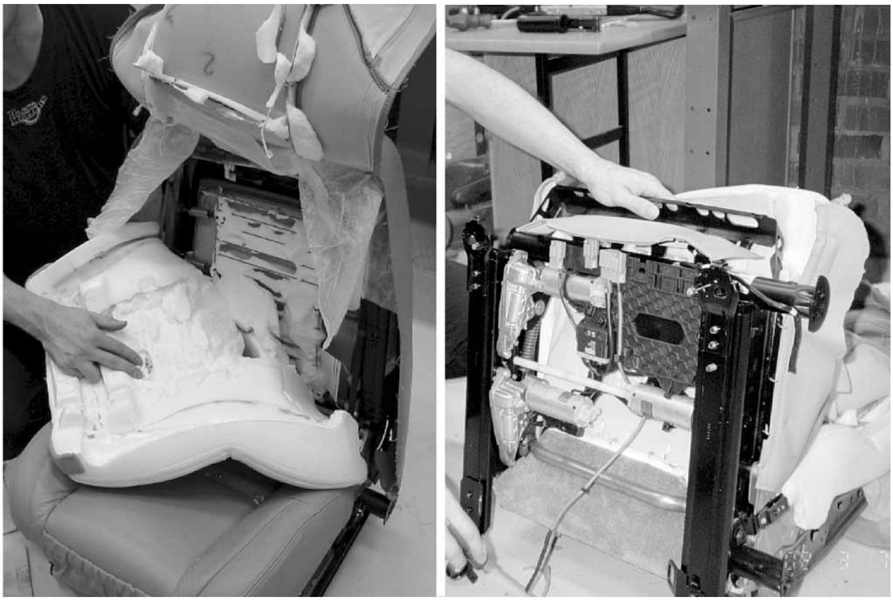

Figure 2. Continued.

proposed to introduce an information package, which could be used internally at the manufacturer to emphasize the disassembly issues. Another suggestion was to develop and formalize an organization within the manufacturer to promote communication between the recycling representative and design engineers.

Thus, the workshop appeared to be successful by bringing together dismantlers and design engineers and generating new ideas on DFD/DFR. Success was also implied by favourable scores on the evaluation questionnaire.

4. Discussion

4.1. *Methodological considerations*

The interviews of the three groups of stakeholders and the authors' site visits brought about a consistent description of present and expected future car disassembly production systems, as well as design for disassembly/recycling (triangulation, Miles and Huberman 1994). There were no obvious divergences in the opinions and viewpoints. However, the opinions given by one dismantling representative were more sophisticated and specific especially about future disassembly production systems. This may be due to the respondent's specific experience in the branch as well as concrete investment plans for ELV line-systems.

The companies investigated (with 3–20 employees disassembling 400–2000 cars/year) were representative of the companies in SBR (http://www.sbrservice.se). However, the investigated companies disassembled to a greater extent 'insurance' cars. This may have contributed to the reported good profitability, modest time pressure and few ergonomics problems.

4.2. *Main findings*

This study shows that 'backtrack' (disassembly) factories are in an early stage of development compared to the 'forward' (manufacturing) factories. This is true for the products as well as the production systems. In spite of this, the physical exposures seem in general to be modest and the industry seems to offer a reasonable profitability when it focuses on dismantling of valuable parts. However, the increased legislative demands on future ELV dismantling are likely to change this situation.

4.2.1. *Design for disassembly (DFD) and design for recycling (DFR)*

To facilitate assembly activities and to reduce costs in 'forward' factories, the DFA concept was developed in the late 1970s (Boothroyd *et al.* 2002). An additional benefit was also simplification of products (Kuo *et al.* 2001).

The DFA concept has now been transferred to disassembly, that is products need to be designed for easy disassembly and component recycling in order to reduce their total life-cycle cost (Kuo *et al.* 2001). DFD is related to time demands for dismantling a product; improved DFD is expected to shorten the time. DFR, on the other hand, is associated with the market value of components and materials, an important prerequisite for disassembling a product. Thus, the interdependence of these concepts needs to be contemplated.

Higher market value of the dismantled parts may, in turn, allow for longer disassembly time and thereby reduced time pressure with obvious ergonomic implications. Attempts to create a market value for car glass/windows have been made in Norway (http://www.hasopor.com/meraker.html) and for recycling of plastics in Sweden (the car manufacturer, personal communication).

Car components seem to increase in complexity over time. One good example of this is the investigated car seat today often including, e.g. airbags and electronics. In the interviews it was emphasized that new and more complex car components create a need for increased knowledge and training of disassemblers. Accordingly, educational systems need to be developed to secure good ergonomics practice as well as efficient work performance.

Based on the interviews and the workshop, we observed that manufacturers are aware of the importance of DFD/DFR. This is supported by the considerable resources in terms of working time and other costs allocated by the representatives from the Swedish car manufacturer to the workshop preparation and performance, without any external financial incentives. The study also showed a mutual interest in co-operation between dismantlers and manufacturers. In practice, DFD/DFR issues are inadequately considered by the manufacturer regarding internal organization as well as design engineering. They score low on the list of priorities among representatives of the car manufacturer (disregarding the special-interest persons) (see table 3). This gives, on the other hand, a scope for proactive consideration of ergonomics as well as efficiency issues.

4.2.2. *Production systems*

Facilitation of assembly and disassembly of products by DFA and DFD, respectively, may reduce work exposures on the operator. However, facilitated and thus shorter cycles often imply more repetitive work, which is a risk factor for musculoskeletal disorders if the exposure time is long (Kilbom 1994, Bernard 1997). This development is described as the 'ergonomics pitfall' (Winkel and Westgaard 1996).

Thus, work organization in future disassembly factories becomes a crucial issue. The present study shows that line concepts are anticipated. This is also supported by scenarios described on the Internet (http://www.crs-europe.com). Based on cases from 'forward' factories, line systems imply repetitive and intensive work (e.g. Òlafsdóttir and Rafnsson 1996, Landsbergis *et al.* 1999, Fredriksson *et al.* 2001). Thus, new organizational solutions to the production systems need to be considered. Experiences from alternative organization of 'forward' car factories may serve as inspiration (Engström *et al.* 1996, Kadefors *et al.* 1996, Westgaard and Winkel 1997).

Appropriate production models may depend on the size of future 'backtrack' factories. Regional plants dismantling 8000–9000 cars/year still imply far lower volumes compared to common 'forward' factories. However, for the individual operator introduction of serial lines may imply high repetitive tasks. Thus, selection of a production model is crucial for obtaining 'sustainable' systems, in which operators may work for many years and maintain health (Brödner and Forslin 2002).

However, long-term expectations regarding the development direction of the dismantling industry also include more dispersed supply chains, that is more tiers. Manufacturers of complex car components (e.g. air bags and safety systems) may develop their own facilities to disassemble and recycle their products. Moreover, electronics components dismantled from cars may, in the future, be sent to special facilities for further treatment. Such development is likely to intensify the production systems and thereby workloads. An analogy can be drawn to 'forward' factories where car body assembly plants are separated from component assembly subcontractors. Ergonomic problems may 'expand' from disassembly to other companies and thus become more difficult to handle. Appropriate ergonomics initiatives therefore need to be considered in the planning of future production life cycles of cars.

Another expected long-term trend gleaned from the interviews is that the shredding industry may develop techniques to process whole cars and separate recyclable materials. This may turn disassembly into a process industry and thus eliminate manual jobs including the ergonomics problems.

Policy statements and economic incentives may help to guide such developments in directions that are positive also for workers' health. Such initiatives must be made at the present time, early in this industrial development, to be effective.

5. Conclusions

An explorative study of the car dismantling industry in Sweden today and expected future development has been carried out. Emphasis has been put on new production systems and the possible consequences in terms of workers' musculoskeletal health. The following conclusions can be drawn:

- Presently, business economics are good and worker performance demands are low, with a rich variety of work tasks. Musculoskeletal disorders seem not to be a significant issue.
- This situation is expected to change, in light of new environmental legislation that requires much added work of no commercial value; presumably resulting in the development of new production systems according to prevalent rationalization concepts.

In addition the following recommendations are offered:

- Steps should be taken at this early stage in the development of the car recycling industry to preserve and develop good working conditions, by avoiding the introduction of serial systems with short-cycle, repetitive work tasks.
- A network of key stakeholders from dismantling, manufacturing, branch representatives and authorities should be established to guide the development of the car disassembly industry.
- Organizations funding R&D should develop programs including issues presented in this report (e.g. Bark *et al.* 2002).

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