Operations Planning Issues in an Assembly/Disassembly Environment
Louis Brennan, Surendra M. Gupta and Karim N. Taleb
Northeastern University, Boston, Massachusetts, USA

Introduction
Discrete parts manufacturing represents a significant portion of total manufacturing activity worldwide. As the name suggests, discrete parts manufacturing involves the production of distinct end items such as motor cars, computers, consumer appliances and weapon systems. A large share of discrete parts manufacturing is accounted for by the assembly process.

Traditionally, the manufacturing systems dealing with assemblies have consisted of one way flows, driven by a material requirements planning (MRP) system, with excess and redundant components, subassemblies and assemblies discarded or sent to landfills. However, the conditions in which such systems operate are changing. There are new forces at work, such as increased awareness of the state of the environment by both the consumer and the producer, recycling regulations and resource conservation needs. These changes lead to new challenges and dictate a fundamental reappraisal of the traditional manufacturing paradigm.

The more forward-looking companies are sensing opportunities arising from this changing environment. Thus, item segregation (i.e. the separation of a part or a group of parts from an assembly by following a reverse assembly process) is already being facilitated by the establishment of some disassembly plants and the creation of product designs which specifically consider disassembly requirements. Once segregated, items can be reused, recycled or stored for future use. Companies such as BMW are already active in the area of disassembly and have established a disassembly plant for item segregation.

While the changes identified above in the operating environment are the major drivers of item segregation, there are also benefits in the area of operations planning and control. Such benefits as increased system flexibility and capacity would be particularly likely in situations where a large degree of inter-product component commonality existed. In such cases, lead time reduction is also possible.

Demand for segregated items is driven by a multitude of stimuli, e.g. external demand, regulatory requirement, internal demand (market driven) and competitive (strategic) initiatives. While only a few examples exist at present, the combination of forces cited above and other factors make the proliferation of item segregation activities across the range of discrete manufacturing inevitable. This phenomenon will be a permanent feature of mass
manufacturing operations. There are, however, problems associated with item segregation. Foremost among these are:

- There are no documented and economically proven planning and scheduling mechanisms in place to deal with item segregation.
- Compared with the traditional manufacturing systems, the material flow is reversed in the item segregation process. This necessitates additional lines to accommodate the reverse flow.
- There is a tendency for item explosion to occur because of the release of multiple subassemblies/components which constitute the assembly.
- Since some assembly processes will utilize the output of item segregation, there will be an impact on their lot sizing procedures.

Despite the economic and environmental benefits of disassembly, researchers and practitioners are lagging behind in the development of methodologies to address the operations and production planning and control issues associated with item segregation. This article addresses these issues.

**Literature Review**

Even though disassembly is a relatively new area, there is a lot of interest in disassembly among manufacturers, governments and consumers. However, there is still no technical literature available dealing with scheduling and inventory problems of disassembly and its impact on existing assembly operations. Most of the articles in the literature tend to deal with these topics at a general level[1-40].

Of these articles, most are specific to motor cars and appliances or deal with design aspects of disassembly. Some manufacturers have already set up disassembly plants and are disassembling products on a pilot basis. It appears that companies such as car and appliance manufacturers that engage in high volume production generating huge amounts of ferrous and plastic waste are most actively pursuing disassembly. Such firms are most likely to be affected by recycling regulations. Foremost among the car manufacturers are BMW, Volkswagen and Audi. For example, BMW has opened such a plant where five cars are dismantled every day and problems arising from disassembly are studied[26]. An Italian firm leads the appliance sector with a dishwasher designed for disassembly, and a US firm already has an electric kettle on the market which can be easily disassembled[5]. It is estimated that European manufacturers are over a year ahead of the rest of the world in disassembly research[16].

By contrast with the literature on disassembly, the literature on MRP is very rich in technical papers (for example [41,42]). MRP is a set of procedures which transforms a demand forecast for a certain product into a schedule of requirements for the components, subcomponents, and raw materials which constitute the product. MRP is therefore a systems approach to production planning which allows the management of inventory in multi-stage production
systems. The technical aspects of disassembly are anticipated to share some common features with MRP. This is because they are both governed by dependent demand concepts and they are both part of a dynamic system operating within a constrained environment. Thus the experience already gained in operating MRP systems should prove to be very beneficial in developing disassembly systems.

Disassembly
Disassembly is the process of systematic removal of desirable constituent parts from an assembly while ensuring that there is no impairment of the parts due to the process. There are both economic and environmentally sound reasons for disassembly:

- Discontinued products. A suddenly discontinued product line can lead to excess inventory of undesirable assemblies. Disassembly scheduling can be used to retrieve valuable components (or components in short supply) which are common to other products still being produced. The remainder are recycled, sold or stored for future use.
- Reduction in lead time. Certain products might have to be disassembled in order to recover some of their subassemblies/components which are scarce and are in urgent demand by some other products. In such a situation, procuring the subassemblies/components needed for the urgent demand product(s) by disassembling other products may result in a substantial lead time reduction for these urgent products.
- Forced disassembly. A plant may be forced to disassemble inventories (before discarding) in order to comply with recycling regulations imposed by governments.

Issues and Research Needs
There are many issues and research needs in the area of disassembly. These can be classified into two broad categories, namely, technical and operational.

Technical Problems
Perhaps the most significant technical challenge lies in the design of the product. Designing a product with “easy” assembly constraints as well as “easy” disassembly constraints is likely to be a very difficult task. The current maturity level of product designs is mostly limited to assembly manufacturing. Disassembly is a new domain and the leading manufacturing companies have only recently realized its importance. In the past, products and machines were designed with only the assembly operations in mind. Now, designers have to think in terms of disassembly and parts recycling as well. Some of the design problems that need specific attention are:

- Ease of separation. Design for ease of separation, handling, and cleaning of all product components.
Low energy usage. Design should aim at reducing energy usage for assembly as well as disassembly.

New fasteners. New two-way snap-fit or pop-in pop-out fasteners should be developed, and existing ones should be improved. Screws, glues and welds should be replaced by other fastening methods. Taking apart a snap-fitted or pop-in pop-out product is much easier and requires less energy than taking apart a welded product.

Precision moulds. Moulds should be designed to tighter tolerances so that the individual snap-fitted parts “stick” well to each other. Large tolerances with a snap-fitted product will reduce its lifetime and make it noisy when handled.

Materials selection. The variety of material types has to be minimized in order to realize volume advantage from the building of large and efficient plants for recycling. Highly recyclable materials such as aluminium and thermoplastics should be encouraged, while minimizing the use of thermosets which cannot be recycled.

Parts consolidation and product structure compression. The product design should minimize the total number of stations and operations. Product structure compression is desired along with parts consolidation and commonality. This will allow easy sorting of the various components for recycling as well as easier assembly/disassembly operations involving fewer steps.

Technical problems with existing products. Manufacturers may not be willing to redesign successful products completely and will only try to comply with disassembly constraints in their newer models. These modified designs for disassembly, which have not been initially conceptualized with disassembly in mind, may face some problems that affect their quality and reliability.

Operational Problems
Manufacturing a product used to be a one time activity: once the product was manufactured and sold, it rarely came back to the plant. Instead, it ended up in a landfill at the end of its useful life. In a disassembly environment, however, old products will have to come back to a disassembly plant, and the components recovered will be re-sold or reused in the assembly plant or recycled at a separate recycling plant. The major operational problems that are likely to arise when dealing with disassembly are:

Accumulations. There will be accumulations of certain kinds of materials. This is because of the disparity between the demand for subassemblies/components and their yield from the assembly. This is due to the multiple sources of demand which act independently of their yield from each assembly. This is complicated by uneven market and/or uneven internal demands leading to undesirable/excess inventories. This
problem is currently most severe in the car industry which generates huge numbers of items such as tyres and windscreens with no market value and high disposal cost.

- **Location problems.** Plant location decisions are influenced by the transportation cost of raw materials. However, when dealing with assembly, disassembly and then recycling, a certain product and its components will have to be present at different locations at different times. The “controlled” traffic for every product is expected to increase several fold. Therefore, the transportation cost proportion of a product over its lifetime is likely to become much larger. Manufacturers will have to consider this problem and plan the locations of new assembly, disassembly or recycling plants appropriately. The recycling operations for some processes can be done in the original production plant. Thermoplastics, for example, which are likely to be more common in a disassembly environment, can often be recycled by simply being fed again into the hopper of the injection moulding machine.

- **Networking problems.** Currently, most operations are planned to revolve around one entity: the assembly plant. In a disassembly environment, however, there will be potentially three separate entities: the assembly plant, the disassembly plant and the recycling plant. Operations therefore have to be planned from a larger perspective that comprises those three entities. Thus, we shall probably be dealing with a network whose nodes are: manufacturing plant, disassembly plant and recycling plant.

- **Resource availability and allocation problems.** Disassembly requires additional work and resources are likely to become a more frequent constraint. This is especially true in the initial transition period when plants are experimenting with disassembly and may be using the same location for production as well as disassembly.

- **Scheduling problems.** Scheduling problems already exist for assembly operations and will change under disassembly, whether a firm decides to disassemble its products in the same location or a different one.

- **Added confusion.** Disassembly increases the operational scope of a firm and makes the system more complex. If disassembly were to be performed in the same assembly plant, the potential for added confusion on the manufacturing floor is significant. This problem should be addressed in terms of plant layout, material handling and parts coding.

- **Buffer stock location(s).** In a disassembly environment, the finished product, the subassemblies and the parts all have a significant dollar value and a significant demand. This will alter the optimal inventory policies in terms of the level and location of buffer stocks. Unexpected demand/breakdowns have to be buffered at both sides of the product structure.
Alternative disassembly sequences. Currently, cars are being disassembled in the pilot plant of BMW in exactly the opposite sequence of assembly. Disassembly, however, may be more efficient if the steps are different. This may be the case when there is a sudden demand for a particular part which needs to be recovered as quickly as possible. This problem remains unexplored.

Implementation and transitional problems. While companies may have a clear idea of where they want to be, they may not know what is the most efficient way to get there. Transitional and implementation problems, when going from assembly to assembly/disassembly, need very careful scrutiny since they have the potential of adding significant cost.

**Operational Impact of Incorporating Disassembly**

**Impact on Product Cost**
The cost of labour, energy and overheads represents a large portion of the total cost of a product. In an assembly/disassembly environment, this cost will be incurred twice: once during assembly and another time during disassembly. Since this will result in more expensive products in the future, manufacturers will start designing products with longer lives so that they are more attractive to consumers. Since longer life products will be of prime importance, quality and reliability will be more important than ever. Manufacturers will therefore have to invest more money in the product itself, from development to manufacturing, so that they can provide better quality and more reliable products.

**Impact on Maintenance**
Maintenance and servicing of products are essential ingredients in ensuring longer product lives. Often these activities require partial disassembly in order to replace or repair parts that are embedded deep in the product structure. The inclusion of design for disassembly considerations in the product design process can greatly facilitate the performance of these activities. In fact, some initial research work has recently been reported in this area[43-45].

**Impact on Financial Decisions**
Under assembly, the capital budgeting process for developing and manufacturing a new product considers a planning horizon that is about equal to its product life-cycle. This process will be more difficult under disassembly because disassembly scheduling requires a much longer planning horizon with increased uncertainties.

**Impact on Capacity and Storage Requirements**
Perhaps the most difficult variable to forecast is the distribution of the returns of used products over the planning horizon. Governmental regulations are expected to force manufacturers to take back their used products when consumers decide to return them. This will be difficult to predict.
Manufacturers may be faced with unexpected return patterns that will depend on their product success in the market and competing products.

Companies have a hard enough time forecasting the demand for new products. Forecasts for the distribution of returns over a period of five or ten years will be subject to huge variations. If a product is successful, then the return pattern is likely to be spread over a longer period. If the product turns out to be unsuccessful, or competitors introduce a better product, then the returns may have a huge volume over a short period and manufacturers will be expected to deal with such a situation.

This problem has definite implications in terms of capacity and storage areas planning for disassembly operations. It could be a huge strain on the capacity of disassembly. Since the returns are most likely to persist over a long period of time, the disassembly machines will have a small capacity while designed to run for long periods of time.

In order to reduce variability, companies will seek to become self-sufficient to the extent that they will own recycling plants whenever they can. This will give them more freedom to handle cost variability and they will be less dependent on market prices for recyclable materials. Small and medium-sized companies which cannot have their own recycling plants will probably build long term alliances with recycling companies. Firms will also try to contain price variability by dealing with long-term trading contracts with the suppliers and recycling plants.

**Research Approaches**

Disassembly is a new area in operations management with a large number of problems and special situations which need to be addressed. While assembly and disassembly have similarities, there are also differences between them. Some of the similarities include dependent demand concepts which relate to scheduling in discrete parts production systems. Other similarities include the general assumptions for an assembly system that remain unchanged for a disassembly environment. Finally, there is a whole class of constraints which is shared by assembly and disassembly problems such as order due dates, setup time/cost of changeovers, and precedence relationships in routing.

As to the differences between assembly and disassembly problems, perhaps the single most important difference is the number of demand sources. In an assembly setting, the parts tend to converge to a single demand source as they are moving on the manufacturing floor. This single demand source is the final product, and the material management’s governing principles are constrained by this convergence property. Under a disassembly setting, as the parts start moving away from their source of origin, they tend to diverge from each other and we have to deal with a “divergence” property. While these two classes of problems sound similar, dealing with them requires different approaches. A qualitative comparison of assembly and disassembly systems is presented in Table 1.

It is anticipated that algorithmic and heuristic developments will be the main means of dealing with the new class of problems that is emerging on the factory
floor. Perhaps the single most critical requirement is the development of a scheduling methodology. This should include a systematic approach to scheduling for item segregation from complex assemblies. In particular, there is a need to:

- Determine the quantities (and timings) of complex assemblies required to meet the demand for item(s) contained therein.
- Produce a timetable of the activities necessary to segregate the required items.
- Maintain a record of the ensuing inventory balances.
- Identify the inputs needed to address the accompanying problems that arise because of item segregation (e.g. determination of capacity requirements, layout and storage needs and logistics issues).
- Develop an integrated system that incorporates existing assembly scheduling methodologies and disassembly scheduling methodologies into one scheduling and inventory system. This should provide a generalized scheduling algorithm that can be used for assembly, disassembly, or a combination of the two. A possible approach to the accomplishment of this step might be the merging of MRP logic with the disassembly algorithms and heuristics that emerge from future research.

**Conclusions**

This article is mainly motivated by current trends in the industrial world. As mentioned earlier, there is a powerful trend today towards environmental

<table>
<thead>
<tr>
<th>System characteristics</th>
<th>Assembly</th>
<th>Disassembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Demand</td>
<td>Dependent</td>
<td>Dependent</td>
</tr>
<tr>
<td>2. Demand sources</td>
<td>Single</td>
<td>Multiple</td>
</tr>
<tr>
<td>3. Forecasting requirements</td>
<td>Single end item</td>
<td>Multi-item</td>
</tr>
<tr>
<td>4. Planning horizon</td>
<td>Product life-cycle</td>
<td>Indefinite</td>
</tr>
<tr>
<td>5. Design orientation</td>
<td>Design for assembly</td>
<td>Design for disassembly</td>
</tr>
<tr>
<td>6. Facilities and capacity planning</td>
<td>Straightforward</td>
<td>Intricate</td>
</tr>
<tr>
<td>7. Manufacturing system</td>
<td>Dynamic and constrained</td>
<td>Dynamic and constrained</td>
</tr>
<tr>
<td>8. Operations complexity</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>9. Flow process</td>
<td>Convergent</td>
<td>Divergent</td>
</tr>
<tr>
<td>10. Direction of material flow</td>
<td>Forward</td>
<td>Reverse</td>
</tr>
<tr>
<td>11. Inventory by-products</td>
<td>None</td>
<td>Potentially numerous</td>
</tr>
<tr>
<td>12. Availability of scheduling tools</td>
<td>Numerous</td>
<td>None</td>
</tr>
</tbody>
</table>
awareness, and resource and energy conservation. In terms of governmental controls, environmental objectives can be achieved by imposing new regulations on manufacturers, such as restrictions on the total amount of energy that can be consumed per year, or imposition of fees on disposing of unneeded inventories. Unfortunately for manufacturers, such new regulations are equivalent to a set of new constraints which have to be complied with within a very short time. This requires dealing with a new class of problems for the first time, and perhaps rethinking and redesigning operations from as early as product inception.

Moreover, far from reducing the product cost for manufacturers, environmental regulations will most probably push these costs higher. For example, one car manufacturer is considering adding $1,000 to the price of its cars to cover expenses related to environmental matters[12]. These new constraints and regulations will affect the operations and costs of existing plants in a fundamental manner. Manufacturers will look for ways to stay competitive in this expensive new manufacturing setting. Without a doubt, a structured study of the new kinds of problems that manufacturers will face is crucial at this point in time. Any research in this area will be seminal in nature, and should lay the foundation for enabling manufacturers to remain competitive while satisfying the requirements of emerging environmental constraints.

References