Aggregate Planning for Disassembly Process in Reverse Supply Chain

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Abstract

Disassembly process in reverse supply chain is one of crucial stage due to this process could change returned products into raw material that could be re-used on manufacturing process or sold to third party. This paper will be explained how aggregate planning is used to planned disassembly process. Aggregate planning is considered with an objective on how returned product is disassembled with manpower allocation to fulfilled demand of raw materials. Classical aggregate planning strategy was implemented either level or chase strategy. A case study in small medium enterprise that dealing with electronics device waste was observed. Phone and tablets as one of electronics device was considered as products to be examined. The disassembly process will be evaluated and some aggregate planning scenarios will be introduced to maximize disassembly units as well as minimize the disassembly process costs. The optimized scenarios where all returned product could be disassembled at minimum cost will be presented.

Keywords
Disassembly planning; Aggregate planning strategy; Reverse supply chain

1. Introduction

A circular economy has pushed the frontiers of environmental sustainability by emphasizing the idea of transforming products in such a way that there are workable relationships between ecological systems and economic growth (Genovese, Acquaye, Figueroa, & Koh, 2017). For an example, resources are kept in use for as long as possible, extracting the maximum value from them whilst in use, then recovering and regenerating products and materials at the end of their life. In this context the concept of Reverse Supply Chain (RSC) has been developed as an adaptation of the circular economy principles to supply chain management (Butar Butar & Sanders, 2016). RSC also mentioned as the collaborative responsibility of both the producers and consumers to reduce the waste by recycling, remanufacturing, reusing, and properly disposing unacceptable products or items to enhance the environmental sustainability (Bouzon, Govindan, Rodriguez, & Campos, 2016; Govindan, Palaniappan, Zhu, & Kannan, 2012). Increasing attention has been given to the RSC due to the increasing value of products and technology at the end of direct supply chains as well as the impact of green legislation.

The RSC is an essential part of sustainable supply chain management. It helps in reducing the quantity of waste sent to landfill by extracting maximum value out of the end of life/use products. It is essentially specifically in case of electronics returns, as there is a steady increase in the number of e-waste due to fast paced growth in technology (Mathiyazhagan et al., 2020). Collection of E-waste for reuse, recycling, remanufacturing and proper disposal of E-waste has become a European law in 2003 (Georgiadis & Besiou, 2010). Product returns and their reverse supply chains represent an opportunity to create a value stream, not an automatic loss. Then, RSCs should be managed business processes that can create profit for a company (Butar Butar, Sanders, & Frei, 2016). Being a part of reverse flow in closed-loop supply chain (CLSC), the disassembly process is the essential step enabling the circular economy (Habibi, Battaïa, Cung, & Dolgui, 2017).

1.1 Objectives

The objective of the research was to purposed company several scenarios in order to find the best resource allocation by implementing classical aggregate planning strategy. Level and chase strategy will be used to found the optimize worker and maximum disassembly return products. This paper will focus on disassembly process in RSC, particularly on electronics recycling facilities. This paper was based on research in small medium electronics company at Depok, Indonesia. Disassembly process on returned products were investigated and aggregate plan will be presented based on manpower that available. Scenarios will be introduced to maximize disassembly units as well as minimize the disassembly process costs for company to be considered in the future. This paper introduces:

- An adapted model for returned product flow.
- A mathematical model for aggregate planning in disassembly process.
- An aggregate planning using level and chase strategy.

2. Literature Review

In RSC, there are additional processes when compared with forward supply chain. The processes are dependent on the condition (quality) of the returns and appropriate channels are chosen based on recovery options. Products are returned for many reasons, such as defects, end of useful life, or the product does not meet a customer's needs (Butar Butar & Sanders, 2016). Figure 1 systematically address the products returned at each process stage along the supply chain.

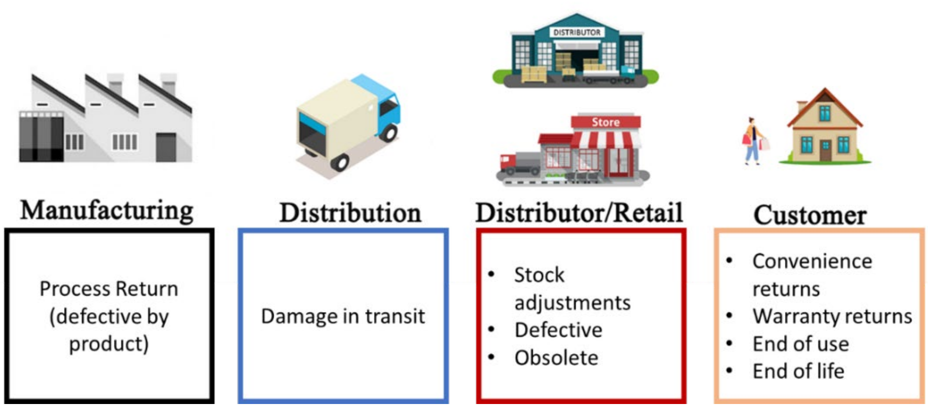

Figure 1. Types of products from each process stage (Butar Butar & Sanders, 2016)

The next element that was explored regarded the outputs or consequences of the RSC process. RSC objectives are the reusing, recycling, remanufacturing, disposal, reducing, and recapturing value of the "inputs" (Butar Butar & Sanders, 2016). Kushwaha, Ghosh, and Rao (2020) provided brief definitions of each disposal option of RSC as follows:

- Reuse – the packaging is reused or a product is sent back for resale to another customer.
- Repair/repackage – where a moderate amount of repair and/or repacking will allow the product to be reused.
- Recycling – where the product is broken down and "mined" for components that can be reused or resold.
- Reconditioning – When a product is cleaned to its basic elements, which are reused.
- Refurbishing – Similar to reconditioning, except with perhaps more work involved in repairing the product.
- Remanufacturing – Similar to reconditioning, but requiring more extensive work; often requiring complete disassembling of the product.

The recycling business including recovery process, re-manufacturing and recycling operations, has been regarded as a promising branch of sustainable operations in production management (Jaehn, 2016). Recycling requires disassembly process of parts where they are separated to acquire distinct materials. The original physical and functional structures are not retained.

Disassembly Process

The end-of-life (EOL) products or components delivered to the disassembly plant will be processed by disassembly operations, producing the disassembled parts for the reuse, remanufacturing or recycling (Zhou, He, Ma, Lim, & Pratap, 2022). Gungor and Gupta defined disassembly as: "a systematic method for separating a product into its constituent parts, components and subassemblies". Disassembly could be partial or complete, as well as destructive or no-destructive. In disassembly process that happened after EOL product or components no-destructive disassembly take place in which component removed without affecting the others (Mitrouchev, 2015). Disassembly processes is not similar to assembly process, in disassembly process the final objective is to minimizing the environmental affect as well as maximizing profits.

Disassembly process usually took place in recovery center to facilitate disposal and remanufacturing procedure. Recovery center who collects returned products (EOL Products) from customer, responsible for operation in component disassembly, classification, inspection and repair. From this process, secondary materials included parts and raw material could be provided. Furthermore, disassembly process also produced semi-finished goods for sale to third party (Cao et al., 2018).

The returned products were collected (in product collection process) from many widespread sources and consolidated for further inspection, handling and processing. Re-sale-able product will be sorted and delivered to second market to be sold as second item or refurbishment products. Disassembly process took place in order to process non-resale-able product. In Figure 2, simplified flow diagram for recycling of an electronic product is presented. shown that disassembly process occurred only to returned product that not resale-able. This simplified flow diagram will be used as based to described disassembly process in the companies this paper studied.

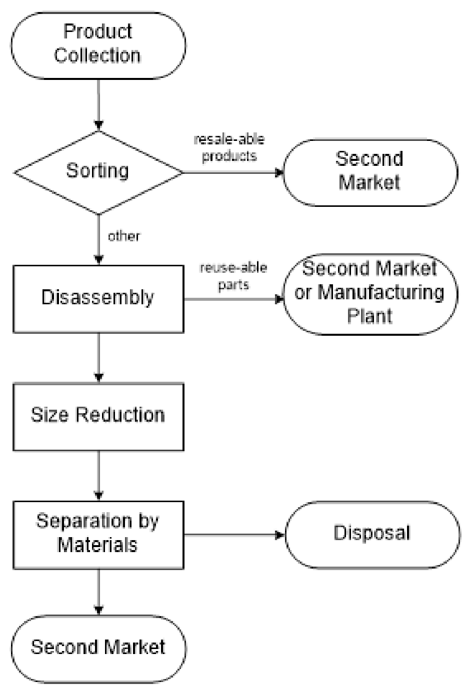

Figure 2. Simplified flow diagram for the recycling of an electronic product (Butar, Sanders, & Tewkesbury, 2014)

Disassembly Planning

Strategic planning is an important process in field of disassembly process. Disassembly planning is important in order to make the recycle process optimized. Disassembly planning has been outlined as important area. However, since the objective of disassembly is the generation of specific fractions of products compatible with the recycling processes and many constraints are always present, in disassembly planning it is generally difficult to find an optimal strategy (Santochi, Dini, & Failli, 2002).

An effective disassembly planning could be used to determine the optimal disassembly depth, it is mean when the disassembly process need to be stopped. Often disassembly planning also used to analyze how to make disassembly process cost to be minimum.

Aggregate Planning for Disassembly Process
Aggregate planning is used in analyze the disassembly planning. Using classic aggregate planning, the company could predict how much labor worker needed and how to meet the best optimal condition. Where, the cost is minimum and the return product is disassembled.

The aggregate planning used to determine the production, inventory and capacity level for each period that maximized company profit over planning horizon. There are two strategies introduced in this paper, level and chase strategy. Level strategy is when production is planned with a steady production rate, this act will occur inventory and holding costs. Meanwhile, in chase strategy, production rate following the demand pattern avoiding inventory and allowing fluctuation in labor requirement, either by overtime or subcontract (Krajewski, 2017).

In this paper, aggregate planning will be used for disassembly process. Where the production rate is the amount of disassembled returned product. Demand in this disassembly process state as all returned product that need to be assembled.

3. Methods

The objective of the research was to purposed company several scenarios in order to optimizing disassembly process by implementing aggregate planning strategy. In this paper a framework of research was made, and shown in Figure 3. A first step was to understand RSC and disassembly process in RSC. Disassembly process and disassembly planning were explored. Definition of aggregate planning is introduced, this explanation continued with an info on aggregate planning for disassembly planning. This was achieved by completing a literature review. Literature review was concluded to learn previous research and gain more knowledge in this area.

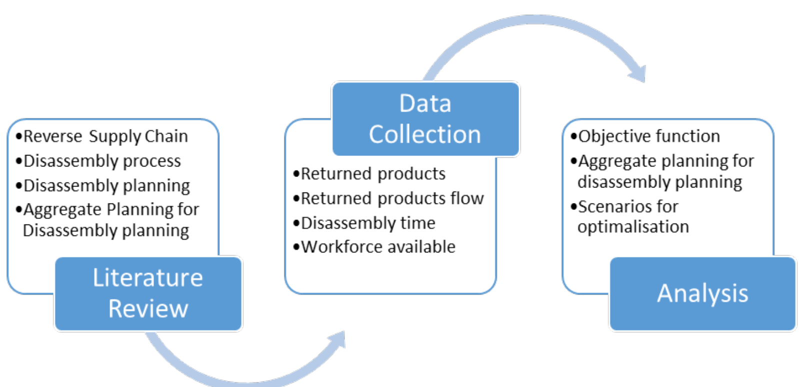

Figure 3. Research methodology

A case study on small medium enterprise that having RSC activities are made. This case study was concluded in electronics recycling company in Depok, Indonesia. The company dealing with electronics especially phone and tablets that collected from several shop that collect electronics from customer. The company choose not to be mention in this paper, therefore in this paper the company will be named as Company X. Several data will be collected, this includes amount of returned product, how returned product processed in the company, time needed for disassembly and how many workers available. This data will be used to analyzed disassembly process in the Company X.

In the next phase, mathematical model with an objective to minimize cost function in disassembly process were presented. Aggregate planning with level and chase strategy were calculated, and several scenarios purposed in order to optimized the disassembly process.

4. Data Collection

Several data collected from Company X. Data were collected in 12 weeks' time period, this data documented between Februari until April 2022. Tablets and phone were selected to be case study due to these two items the most returned product in the Company X. Returned product is presented in Table 1.

Table 1. Returned Product

Time Period (week)	Returned Product (unit)		Average Disassembly Time per unit (minute)		Worker Time available (minute)	
	Phone	Tablets	Phone	Tablets	Phone	Tablets
1	50	25	15	25,5	900	900
2	45	30	14	24	900	900
3	65	29	14,5	24,1	900	900
4	46	19	14,8	24,5	900	900
5	52	21	15	25	900	900
6	39	24	13	24,8	900	900
7	46	26	12,5	25,2	900	900
8	52	24	13,8	25,6	900	900
9	48	30	15,5	25,8	900	900
10	38	24	15,2	25,3	900	900
11	43	26	14,3	25	900	900
12	44	22	13,8	25,3	900	900

The returned product flow was observed, the company received collected electronics item from several shop where returned product collected from customer. Company will receive return electronic product every week usually on Saturday, and will put all returned product in a warehouse before going to sorting process. Sorting process will take in Saturday every week and disassembly process will be held from Monday-Friday. Flow of returned products in the company shown in Figure 4.

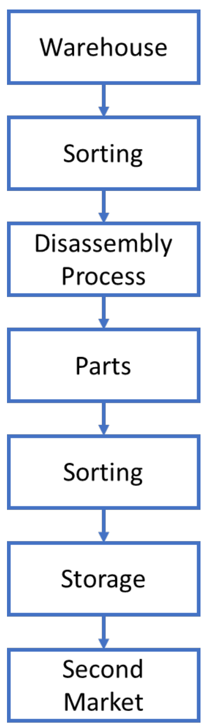

Figure 4. Returned product flow

Disassembly process for tablets and mobile phone presented in Figure 5 and Figure 6. Disassembly process based on observation of worker in the company. In the company there is 1 disassembly stage, from returned product to parts.

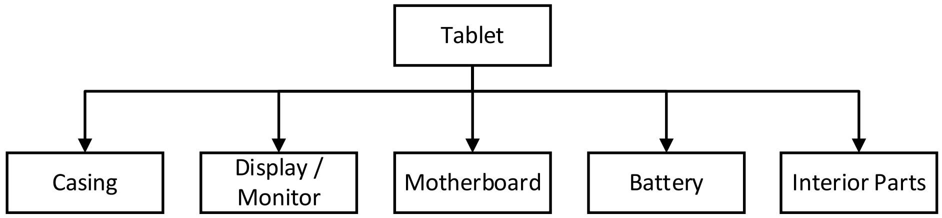

Figure 5. Disassembly for tablet

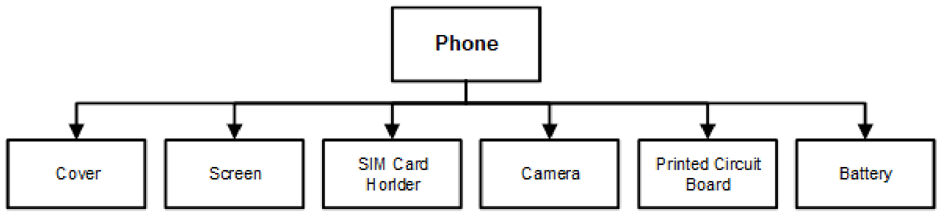

Figure 6. Disassembly for phone

This collected data will be used to calculate aggregate planning in disassembly process. Objective function and mathematical model will be discussed in next chapter.

5. Results and Discussion

5.1 Objective Function

To minimized cost that occur is the objective function in the disassembly process.

$$\text{Disassembly Process Total Cost} = \text{Total disassembly cost} + \text{Total inventory cost} + \text{Total labor cost} \quad (1)$$

Total disassembly cost = disassembly cost x disassembled unit
Total inventory cost = holding cost x stored unit
Total labor cost = labor cost x worker

In this company since returned products was send to recovery center there is no transportation cost occurred from customer to recovery center warehouse. However, there is a transportation cost when Company X make a delivery to second market and landfill (disposal). Total cost in recovery center in Company X was shown in function number 2

$$\text{Disassembly Process Total Cost} = \sum_{i=1}^{I}\sum_{t=1}^{T} RP_{it}D_{it} + \sum_{i=1}^{I}\sum_{t=1}^{T} SP_{it}H_{it} + \sum_{i=1}^{I}\sum_{t=1}^{T} W_{it}L_{it}$$

Where;
I = number of types of product
T = number of periods of time
RP = number units of returned product
SP = number units of stored returned product
W = number of worker or labor
D = disassembly cost
H = holding cost
L = labor cost

With this mathematical model Company X could measure their disassembly cost that occurred in the company.

5.2 Aggregate Planning in Disassembly Process

Two strategies will be introduced in this disassembly planning. Tablet retuned using chase strategy calculation presented in Table 2 and level strategy calculation shown in Table 3. Phone retuned using chase strategy calculation presented in Table 4 and level strategy calculation shown in Table 5.

Table 2. Chase strategy for tablet returned

Period (week)	0	1	2	3	4	5	6	7	8	9	10	11	12
Returned Tablet (unit)	0	25	30	29	19	21	24	26	24	30	24	26	22
Disassembly time (minute/unit)	0	25.5	24	24.1	24.5	25	24.8	25.2	25.6	25.8	25.3	25	25.3
Maksimum Disassembly Capacity (unit)	0	35	37	37	36	36	36	35	35	34	35	36	35
Disassembled Phone (unit)	0	25	30	29	19	21	24	26	24	30	24	26	22
Inventory (unit)	0	0	0	0	0	0	0	0	0	0	0	0	0
Worker Needed (man)	0	1	1	1	1	1	1	1	1	1	1	1	1

Table 3. Level strategy for tablet returned

Period (week)	0	1	2	3	4	5	6	7	8	9	10	11	12
Returned Tablet (unit)	0	25	30	29	19	21	24	26	24	30	24	26	22
Disassembly time (minute/unit)	0	25.5	24	24.1	24.5	25	24.8	25.2	25.6	25.8	25.3	25	25.3
Maksimum Disassembly Capacity (unit)	0	35	37	37	36	36	36	35	35	34	35	36	35
Disassembled Phone (unit)	0	48	48	48	48	48	48	48	48	48	48	48	48
Inventory (unit)	0	0	0	0	0	0	0	0	0	0	0	0	0
Worker Needed (man)	0	2	2	2	2	2	2	2	2	2	2	2	2

Using chase strategy, company require 1 worker to disassembled every tablet returned. While, using level strategy need 2 workers.

Table 4. Chase strategy for phone returned

Period (week)	0	1	2	3	4	5	6	7	8	9	10	11	12
Returned Phone (unit)	0	50	45	65	46	52	39	46	52	48	38	43	44
Disassembly time (minute/unit)	0	15	14	14.5	14.8	15	13	12.5	13.8	15.5	15.2	14.3	13.8
Maksimum Disassembly Capacity (unit)	0	60	64	62	60	60	69	72	65	58	59	62	65
Disassembled Phone (unit)	0	50	45	62	49	52	39	46	52	48	38	43	44
Inventory (unit)	0	0	0	3	0	0	0	0	0	0	0	0	0
Worker Needed (man)	0	1	1	1	1	1	1	1	1	1	1	1	1

Table 5. Level strategy for phone returned

Period (week)	0	1	2	3	4	5	6	7	8	9	10	11	12
Returned Phone (unit)	0	50	45	65	46	52	39	46	52	48	38	43	44
Disassembly time (minute/unit)	0	15	14	14.5	14.8	15	13	12.5	13.8	15.5	15.2	14.3	13.8
Maksimum Disassembly Capacity (unit)	0	60	64	62	60	60	69	72	65	58	59	62	65
Disassembled Phone (unit)	0	48	48	48	48	48	48	48	48	48	48	48	48
Inventory (unit)	0	2	0	17	15	19	10	8	12	12	2	0	0
Worker Needed (man)	0	1	1	1	1	1	1	1	1	1	1	1	1

Company needs 1 worker to disassembled every phone returned, either using level nor chase strategy. Item stored using level strategy is 97 units and using chase strategy 3 units. The comparison between 2 strategies presented in Table 6. Cost was calculated based on the mathematical function, however since the financial in the company is confidential cost will be presented in variable.

Table 6. Comparison between chase and level strategy

Strategy	Tablet		Phone	
	Chase	Level	Chase	Level
Disassembly cost (a)	300	300	568	568
Holding cost (b)	0	0	3	97
Worker cost (c)	1	2	1	1
Total Cost	**300 a + 1c**	**300 a + 2c**	**568 a + 3b + 1c**	**568 a + 97b + 1c**

5.3 Proposed Scenarios

In proposed scenarios, maximum capacity was considered in order to optimize the disassembly process. For tablet returned, 1 and 2 worker scenarios presented. Table 7 shown how many units could be assembled with 1 worker and Table 8 shown if 2 workers involved. While in phone returned, only 1 worker need in level and strategies, therefore one scenario for returned phone presented. Scenario in returned phone with 1 worker shown in Table 9.

Table 7. One worker in tablet returned

Period (week)	0	1	2	3	4	5	6	7	8	9	10	11	12
Returned Tablet (unit)	0	25	30	29	19	21	24	26	24	30	24	26	22
Disassembly time (minute/unit)	0	25.8	25.8	25.8	25.8	25.8	25.8	25.8	25.8	25.8	25.8	25.8	25.8
Maksimum Disassembly Capacity (unit)	0	34	34	34	34	34	34	34	34	34	34	34	34
Disassembled Phone (unit)	0	34	34	34	34	34	34	34	34	34	34	34	34
Inventory (unit)	0	0	0	0	0	0	0	0	0	0	0	0	0
Available disassembly phone (unit)	0	9	4	5	15	13	10	8	10	4	10	8	12
Worker Needed (man)	0	1	1	1	1	1	1	1	1	1	1	1	1

Table 8. Two workers in tablet returned

Period (week)	0	1	2	3	4	5	6	7	8	9	10	11	12
Returned Phone (unit)	0	50	45	65	46	52	39	46	52	48	38	43	44
Disassembly time (minute/unit)	0	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Maksimum Disassembly Capacity (unit)	0	116	116	116	116	116	116	116	116	116	116	116	116
Disassembled Phone (unit)	0	116	116	116	116	116	116	116	116	116	116	116	116
Inventory (unit)	0	0	0	0	0	0	0	0	0	0	0	0	0
Available disassembly phone (unit)	0	66	71	51	70	64	77	70	64	68	78	73	72
Worker Needed (man)	0	2	2	2	2	2	2	2	2	2	2	2	2

Table 9. One worker in phone returned

Period (week)	0	1	2	3	4	5	6	7	8	9	10	11	12
Returned Phone (unit)	0	50	45	65	46	52	39	46	52	48	38	43	44
Disassembly time (minute/unit)	0	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Maksimum Disassembly Capacity (unit)	0	58	58	58	58	58	58	58	58	58	58	58	58
Disassembled Phone (unit)	0	58	58	58	58	58	58	58	58	58	58	58	58
Inventory (unit)	0	0	0	7	0	0	0	0	0	0	0	0	0
Available disassembly phone (unit)	0	8	13	0	12	6	19	12	6	10	20	15	14
Worker Needed (man)	0	1	1	1	1	1	1	1	1	1	1	1	1

These scenarios could give an information to company on how to optimized their disassembly process. Figure 7 shown maximum capacity compare with returned product in every scenario.

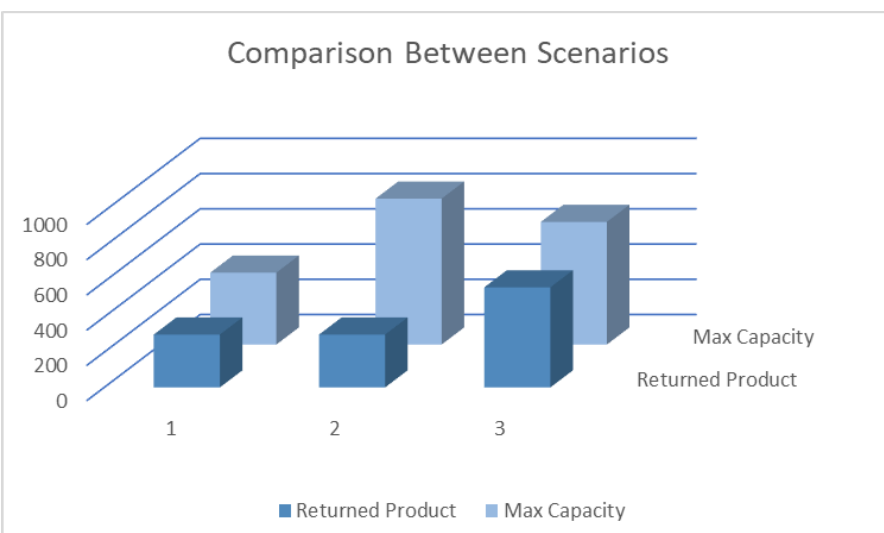

Figure 7. Comparison between scenarios

6. Conclusion

From an investigation of Company X, it was realized that returned products were received at shops or stores from customers. Entire returned product stored at the Company X to undergo disassembly process. The mathematical function described the total cost of disassembly in Company X. From the aggregate planning calculation, Company X still having available source for returned product. More returned product can be disassembled in company X, hence company X should collect more returned product.

In the future, capability of worker concentration should be consider in the aggregate planning calculation.

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Biography

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