Providing a Comprehensive Production Model for the WARP Shoe Company to Maximizes Profits

Nicholas Eckhert | eckhertn | 1010037568

Aditya Mishra | mishr167 | 1009807372

*****All code for this project can be found in our GitHub (link in Appendix A).

Abstract

Following one of their competitors going out of business, the WARP shoe company requested a production plan for February 2006 which maximizes profit considering the rise in demand. As a result, we formulated the problem as an integer program, considering key constraints and aiming to maximize profit. After formulating the model, we estimated demand using holt-winters forecasting and solved our model utilizing gurobi. Our solution projects a profit of $11,777,402.50, by meeting demand for expensive shoe types, coming up short of demand for some shoe types, and not producing the rest. Our solution was bound by the demand and the quantity of raw materials that were available for purchase.

1.0 Introduction

A major competitor of the WARP Shoe Company went bankrupt in the beginning of 2006. As a result, the company believes that in the month of February the demand for all shoes will double and has asked us to devise a production plan for them. In addition, all inventory for the month of January was sold, meaning that the company has no product going into the next month. We also were instructed to follow a given set of considerations [Appendix B]. The following formula was key in formulating our objective function while defining the problem.

Formula One: Profit Formula

$$\text{Pr}\,ofit = Revenue - Costs$$

Since our goal is to maximize profit our first step was to attempt to identify the revenue. As we know the revenue is from the shoes being sold. This raised the question of which shoes, and how many? To answer this, we had to first view the cost of the shoes in the data tables provided, while also understanding the demand. The latter was more complex and resulted in us utilizing Holt-Winter Forecasting.

Our second step was to identify the costs which the WARP Shoe Company business was facing, and through our assumptions, which will be broken, down later we decided on four:

1. Worker Wages
2. Warehouse opening costs
3. Cost of Raw Materials
4. Machine operating Costs
5. Cost of not meeting demand

Once these were identified we utilized multiple programs including: Excel, R, Python and AMPL to construct our model and produce a plan to yield maximum profit.

2.0 Methods

The team chose to define this problem as a maximization integer program.

$I = 557$ is the total number of shoe types, $J = 72$ is the total number of machines, $W = 8$ is the total number of warehouses, and $K = 165$ is the total number of raw material kinds.

We defined the following decision variable:

x_i - the number of shoes produced of the i^{th} shoe type. $\forall\ i = 1, \ldots, I$

y_w - a binary value which takes 1 if the w^{th} warehouse is open and 0 otherwise. $\forall\ w = 1, \ldots, W$

We also defined the following parameters:

D_i - the forecasted demand for the i^{th} shoe type. $\forall\ i = 1, \ldots, I$

n_{ik} - the amount of the k^{th} raw material in one i^{th} type of shoe. $\forall\ i = 1, \ldots, I\ and\ k = 1, \ldots K$

p_k - the unit cost of the k^{th} raw material. $\forall\ k = 1, \ldots K$

m_i - the cost of raw materials for one i^{th} type of shoe where

$$m_i = \sum_{k=1}^{K}(n_{ik} \cdot p_k) \quad \forall\ i = 1, \ldots, I$$

t_{ij} - time to manufacture the i^{th} type of shoe on the j^{th} machine in seconds.

$$\forall\ i = 1, \ldots, I\ and\ j = 1, \ldots J$$

T_{ij} - time to manufacture the i^{th} type shoe on the j^{th} machine in hours where

$$T_{ij} = \frac{t_{ij}}{360}\ \forall\ i = 1, \ldots, I\ and\ j = 1, \ldots, J$$

s_i - sale price of one i^{th} type shoe. $\forall\ i = 1, \ldots, I$

C_w - capacity of the w^{th} warehouse. $\forall\ w = 1, \ldots, W$

h_w - cost to open the w^{th} warehouse. $\forall\ w = 1, \ldots, W$

a_j - cost per minute to operate the j^{th} machine. $\forall\ j = 1, \ldots J$

q_k - quantity of raw material k available. $\forall\ k\ = 1, \dots K$

*All parameters without a defined formula were obtained from the database

Using these parameters and variables we then defined the following model to maximize profit by computing: revenue – cost of employees – cost of not meeting demand – warehouse opening cost – cost of raw materials – cost of operating machines:

Formula Two: Objective Function

$$\max \quad Z = \left(\sum_{i=1}^{I} x_i \cdot s_i\right) - \left(25 \cdot \sum_{i=1}^{I}\sum_{j=1}^{J} T_{ij} \cdot x_i\right) - \left(\sum_{w=1}^{W} y_w \cdot h_w\right)$$

$$- \left(10 \cdot \sum_{i=1}^{I} (D_i - X_i)\right) - \left(\sum_{i=1}^{I} x_i \cdot m_i\right) - \left(\sum_{i=1}^{I}\sum_{j=1}^{J} 60 \cdot a_j \cdot T_{ij} \cdot x_i\right)$$

Formula Three: Demand Constraint

$s.t. \quad x_i \leq D_i\ \forall\ i = 1, \dots, I$ (demand)

Formula Four: Budget Constraint

$s.t. \quad \sum_{i=1}^{I} x_i \cdot m_i\ \leq\ 10{,}000{,}000$ (raw material budget)

Formula Five: Machine Hours Constraint

$s.t. \quad \sum_{i=1}^{I} T_{ij} \cdot x_i\ \leq\ 336\ \forall\ j = 1, \dots, J$ (available machine hours)

Formula Six: Warehouse Capacity Constraint

$s.t. \quad \left(\sum_{i=1}^{I} x_i\right)\ - \left(\sum_{w=1}^{W} c_w \cdot y_w\right) \leq 0$ (available warehouse capacity)

Formula Seven: Raw Materials Constraint

$s.t. \quad \sum_{i=1}^{I} x_i \cdot n_{ik} \leq q_k\ \forall\ k = 1, \dots, K$ (available raw material quantities)

Formula Eight: Integer Program and Non-Negativity Constraints for Each Shoe Type

$s.t. \quad x_i\ \in\ \mathbb{Z}^+\ \forall\ i = 1, \dots, I$

Formula Nine: Binary Constraint for Warehouses

$s.t. \quad y_w\ \in\ \{0,1\}\ \forall\ w = 1, \dots, W$

In this model we make the following assumptions:

1. Workers are paid at a rate of 25$ times the number of hours they worked (including fractional hours).
2. Each machine can only be operated for 12 hours a day.
3. Transportation costs are negligible.
4. Manufacturing sequence is negligible.
5. Machine setup times and costs are negligible.
6. Raw material costs are deducted from total monthly profits, not just the budget.

3.0 Results

This section details the forecasting of our demand, implementation of our model, the recommended solution, and answers to the assignment questions.

3.1 Implementation

Using the model defined in section 2.0, the team first sought to forecast the demand for the month of February 2006. To do so we first extracted the data from the table and formatted it into a CSV with our desired columns using a simple R program. Afterwards, we used a python program to visualize any trends in the data. As seen in figure 1, we found a clear seasonal trend as well as an overall trend over three years when looking at the demand for shoe type "SSH001." As a result, we decided to use python to implement Holt-Winters forecasting due to its ability to capture long-term and seasonal trends. After we completed the forecast, we doubled the values to account for the expected increase in demand.

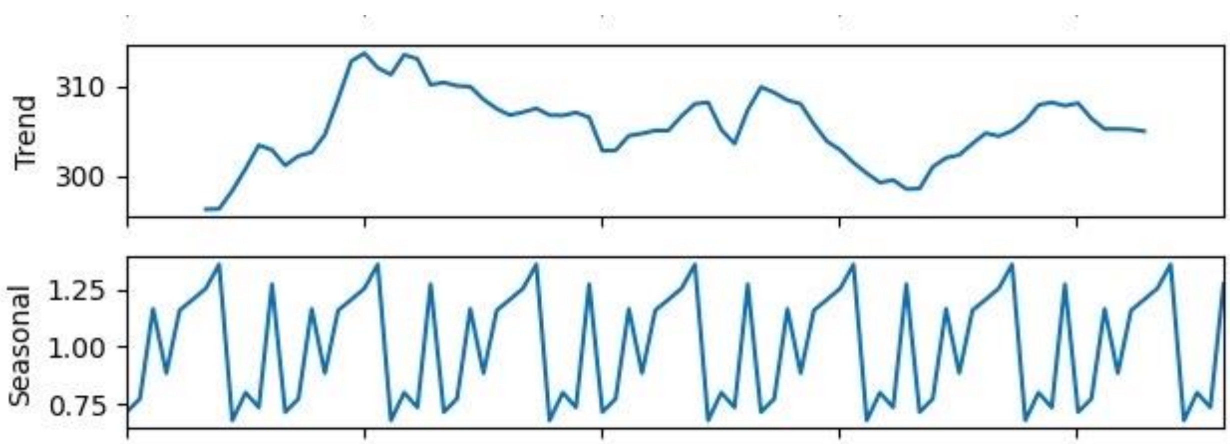

Figure 1. Trends in demand for product "SSH001."

After forecasting demand, we plugged it into our integer program and utilized AMPL to solve our model. Due to computational and time constraints, we were forced to relax our model into a linear program where $x_i \geq 0 \ \forall \ i = 1, \ldots, I$.

3.2 Our Solution

Due to time and computing constraints, we were forced to relax our model to a linear program and then round the received values to the nearest integer after. After solving this program using gurobi, we achieved the following objective function value:

Profit = $11,777,402.50

This suggests that by following our production plan, the WARP Shoe Company could make around this value in profit. Our model's complete recommendations for shoe production can be found in Appendix C. As seen in a snipper of our solution in figure 2, the solution involves production up to demand on some shoes, production short of demand on some shoes, and no production of the remaining shoes. Our solution was bound by shoe demand of expensive shoes and quantity of raw frequently used materials. As a result, to increase profit, it is suggested to either increase demand for expensive shoes or find a way to acquire a larger quantity of frequently used raw materials. According to our model, other changes will yield no improvement in profit.

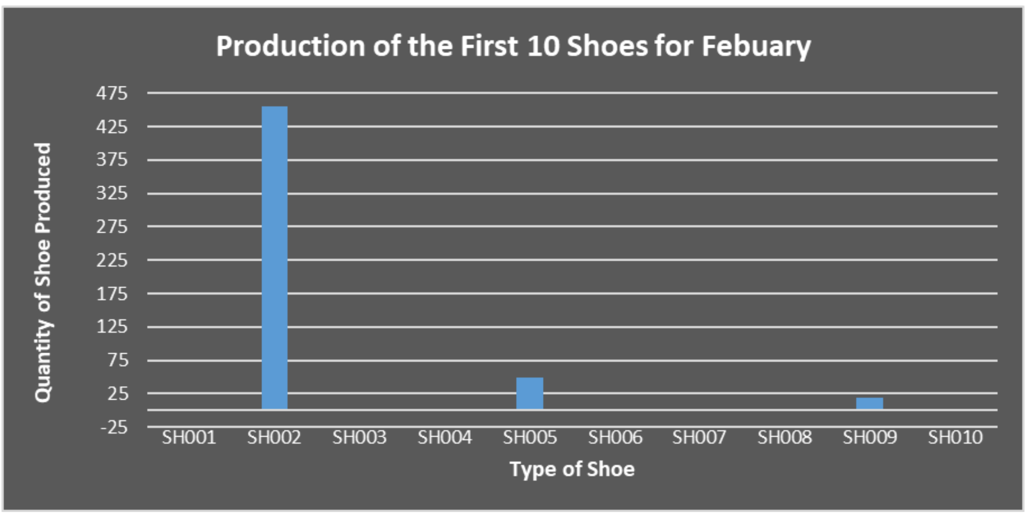

Figure 2. Recommended production for the first 10 types of shoes.

3.3 Answers to Questions

1. How should you estimate the demand for the month of February?

   We started our estimation process by visualizing trends in the demand for the given three years of data where we found both seasonal and long-term trends. As a result, we utilized holt-winters forecasting due to its ability to capture seasonal and long-term dependencies. After we completed the forecast, we doubled the values to account for the expected increase in demand.

2. How many variables and constraints do you have?

   We have two types of decision variables, one representing the number of each shoe type we should produce (577 total variables) and another representing a binary value for whether each warehouse is open or not (8 total variables). We had five types of constraints not including integer non-negativity and binary constraints. We had one constraint type to make sure we didn't produce more shoes than demand (577 total constraints), one to make sure the budget for raw materials wasn't exceeded (1 total constraint), one to make sure more raw materials than we had access to weren't used (165 total constraints), one to make sure there weren't more shoes than capacity (1 total constraint), and one to make sure that available machine hours weren't exceeded (72 total constraints).

3. If you had to relax your integer program to an LP, how many constraints were violated

after rounding the LP solution to the closest integer solution?

After rounding out to the nearest integer solution, we violated 68 total constraints from the demand constraint type (41 total constraints violated) and the raw materials quantity constraints (27 total constraints violated). A full list of violated constraints can be found in Appendix E.

4. Which constraints are binding, and what is the real-world interpretation of those binding constraints?

There are two binding constraints: shoe demand for some shoes and available raw material quantities for most raw materials. A list of the specific binding constraints can be found in Appendix D. The real-world interpretation for shoe demand is the fact that we produce exactly the demand for some shoes. This makes sense since we would not want to produce more than the demand. The real-world interpretation for the raw materials quantity constraint is the fact that we utilize all of the available raw materials. This makes sense since we cannot use materials that we don't have access to. Additionally, non-negativity is binding for some shoes which makes sense since we cannot make negative shoes.

5. Assume that some additional warehouse space is available at the price of $10/box of shoes. Is it economical to buy it? What is the optimal amount of space to buy in this situation?

No, it is not economical to buy it since the warehouse capacity constraint isn't binding, has a slack of 4406. So, we have the ability to store 4406 shoes before we need to change our current solution. Incidentally, this constraint has a shadow price of 0. This means that for each additional box of capacity you buy, the objective function value will increase by $0. This means if we spent money on buying the boxes we would net –$10 for every additional box of capacity purchased. As a result, we should not buy any additional storage.

6. Imagine that machines were available for only 8 hours per day. How would your solution change? Which constraints are binding now? Does the new solution seem realistic to you?

After re-solving the LP with an updated machine hours constraint, our objective function and optimal solution are exactly the same as in our original formulation. This is expected since none of the machine hour constraints were originally binding. This means that in our original solution we are not utilizing all the machine hours, this could be a result of the additional cost accrued through machine operating and worker costs. The demand and raw materials quantity constraints are still the only binding constraints. This solution does not seem very realistic since it implies that we aren't using at least 112 hours of the available time on the machines in our original solution, and decreasing the available time has no effect.

7. If in addition there were a $7,000,000 budget available to buy raw materials, what would you do? Change your formulation and solve again.

Again, the objective function does not change since we run out of available raw materials before we are able to spend our initial budget of $10,000,000. As a result, simply adding to the budget will not increase our total profit and resolving the LP yields the same results as the initial formulation. Therefore, there is no need to attain additional raw materials budget.

4.0 Conclusions

WARP shoes are a company which gave us a very particular set of conditions for the month of February, and we have used these to output the best possible solution for them with the data provided to maximize profit. In the model constructed we introduced assumptions in the methods section, forecasted demand using Holt-Winters, and utilized multiple tools ranging from R to AMPL to find the maximum profit.

When first viewing the problem, we needed to break down the specific costs that the WARP Shoe Company's products incurred. Once we identified these costs, we were able to create an objective function which provides the profit. Our next step was to meet the set of constraints outlined by the WARP Shoe Company. These ranged from machine hours to raw materials. Following this we decided to understand the next key component in our model: the demand. In R we were able to extract the demand data from the CSV files. We then utilized a Python script to visualize trends and found a specific trend for the Shoe model with item code "SSH001". This led to us creating a Python script to complete our Holt-Winters Forecasting.

Through all of these steps we were able to conclude that the maximum profit the WARP Shoe Company can make is $11,777,402.50.

In our model the one constraint which we found the most binding was the raw materials constraint, specifically how many raw materials we have available to us. As can be seen, even if we had a higher budget, more capacity in our warehouses, or less time on our machines: our solution doesn't change. However, due to the raw materials being limited in quantity and there not being enough demand, we shouldn't produce more shoes. Therefore, if the WARP Shoe Company wants to increase its profits further our recommendation would be to either find more suppliers or find suppliers who can provide more raw materials. Additionally, they would have to increase their marketing budget or change consumer behavior to create more demand for their products. Through both these strategies they would be able to increase profits even further.

There are also a few limitations in this model, firstly the way during our forecasting we utilized SH001 to visualize any trends meaning we may have a model which does not perfectly predict demand for all shoes. Another limitation of the model is the fact that we made a set of assumptions on worker wages specifically that they're not paid to the nearest whole hour. This might not actually be true in the real world and is a consideration which could be adjusted to reflect costs differently.

Our model is largely reflective of the real world, but if we were to deepen it, we could factor in additional costs such as transportation. Ultimately, we have largely captured the WARP Shoe Company's model for profitability and believe that the optimal profit provided is accurate to current conditions.

Appendices

Appendix A: GitHub Link

https://github.com/neckhert/WARP-Shoes-Project

Appendix B: List of Considerations

Budget for Raw Materials: **$10,000,000**
Sales price on shoes remain the **same** as in the **Product Master Table**
Not meeting the demand for any type of shoe means the **loss of new potential customers** and hence has been evaluated at a **cost of $10/pair**. Demand for each month from **1997-2003** can be found in the **Product_Demand table.**
During **February 2006** the WARP shoe production plant, including all machines, will work up to **12 hours a day, 28 days a month**. The **cost** of operation of each machine is given in the **Machine_Master** table. Assume that **setup times and costs are negligible**. The **amount of time** (s) each shoe requires from each machine is given in the **Machine_Assign** table.
Workers are **paid** on an hourly basis at the rate of **$25/hour**. Each machine has to be operated by **one worker.**
The **total** warehouse capacity can be obtained from the **Warehouse_Master table**.
Transportation costs can be ignored.
The manufacturing sequence can be ignored.

Appendix C: Recommended shoe production based on our model.

Shoe Type:	Quantity	Shoe Type	Quantity	Shoe Type	Quantity	Shoe Type	Quantity	Shoe Type	Quantity	Shoe Type	Quantity	Shoe Type	Quantity
SH001:	0	SH041:	310	SH081:	157	SH121:	504	SH161:	0	SH201:	473	SH241:	376
SH002:	455	SH042:	215	SH082:	295	SH122:	0	SH162:	0	SH202:	0	SH242:	0
SH003:	0	SH043:	0	SH083:	0	SH123:	0	SH163:	0	SH203:	518	SH243:	0
SH004:	0	SH044:	446	SH084:	0	SH124:	0	SH164:	0	SH204:	0	SH244:	235
SH005:	50	SH045:	384	SH085:	0	SH125:	0	SH165:	467	SH205:	130	SH245:	0
SH006:	0	SH046:	0	SH086:	0	SH126:	72	SH166:	0	SH206:	0	SH246:	0
SH007:	0	SH047:	409	SH087:	434	SH127:	395	SH167:	0	SH207:	4	SH247:	424
SH008:	0	SH048:	266	SH088:	426	SH128:	0	SH168:	402	SH208:	0	SH248:	15
SH009:	19	SH049:	0	SH089:	0	SH129:	0	SH169:	0	SH209:	431	SH249:	415
SH010:	0	SH050:	431	SH090:	465	SH130:	109	SH170:	0	SH210:	0	SH250:	0
SH011:	437	SH051:	0	SH091:	0	SH131:	0	SH171:	0	SH211:	0	SH251:	0
SH012:	258	SH052:	0	SH092:	47	SH132:	0	SH172:	43	SH212:	0	SH252:	0
SH013:	431	SH053:	0	SH093:	313	SH133:	118	SH173:	308	SH213:	441	SH253:	377
SH014:	0	SH054:	0	SH094:	303	SH134:	486	SH174:	0	SH214:	0	SH254:	483
SH015:	0	SH055:	0	SH095:	435	SH135:	0	SH175:	0	SH215:	0	SH255:	148
SH016:	0	SH056:	0	SH096:	466	SH136:	0	SH176:	455	SH216:	0	SH256:	435
SH017:	0	SH057:	188	SH097:	0	SH137:	0	SH177:	0	SH217:	195	SH257:	0
SH018:	246	SH058:	430	SH098:	0	SH138:	0	SH178:	138	SH218:	0	SH258:	0
SH019:	209	SH059:	0	SH099:	0	SH139:	0	SH179:	132	SH219:	0	SH259:	0
SH020:	0	SH060:	201	SH100:	0	SH140:	0	SH180:	0	SH220:	0	SH260:	0
SH021:	0	SH061:	156	SH101:	0	SH141:	0	SH181:	0	SH221:	469	SH261:	419
SH022:	0	SH062:	463	SH102:	0	SH142:	419	SH182:	0	SH222:	0	SH262:	394
SH023:	0	SH063:	441	SH103:	0	SH143:	0	SH183:	0	SH223:	408	SH263:	0
SH024:	408	SH064:	19	SH104:	0	SH144:	456	SH184:	86	SH224:	444	SH264:	0
SH025:	405	SH065:	375	SH105:	419	SH145:	0	SH185:	402	SH225:	444	SH265:	413
SH026:	0	SH066:	0	SH106:	229	SH146:	511	SH186:	20	SH226:	423	SH266:	0
SH027:	424	SH067:	0	SH107:	48	SH147:	62	SH187:	120	SH227:	285	SH267:	0
SH028:	0	SH068:	1	SH108:	0	SH148:	0	SH188:	201	SH228:	0	SH268:	0
SH029:	393	SH069:	0	SH109:	0	SH149:	67	SH189:	0	SH229:	0	SH269:	435
SH030:	0	SH070:	0	SH110:	415	SH150:	445	SH190:	0	SH230:	49	SH270:	52
SH031:	332	SH071:	409	SH111:	0	SH151:	0	SH191:	78	SH231:	0	SH271:	0
SH032:	498	SH072:	30	SH112:	0	SH152:	0	SH192:	0	SH232:	440	SH272:	0
SH033:	0	SH073:	354	SH113:	467	SH153:	131	SH193:	0	SH233:	446	SH273:	305
SH034:	370	SH074:	0	SH114:	0	SH154:	447	SH194:	266	SH234:	412	SH274:	82
SH035:	0	SH075:	0	SH115:	0	SH155:	0	SH195:	233	SH235:	458	SH275:	0
SH036:	0	SH076:	34	SH116:	203	SH156:	0	SH196:	0	SH236:	480	SH276:	233
SH037:	0	SH077:	169	SH117:	44	SH157:	0	SH197:	442	SH237:	0	SH277:	414
SH038:	483	SH078:	400	SH118:	297	SH158:	0	SH198:	0	SH238:	366	SH278:	0
SH039:	392	SH079:	221	SH119:	10	SH159:	0	SH199:	0	SH239:	91	SH279:	0
SH040:	426	SH080:	414	SH120:	0	SH160:	14	SH200:	0	SH240:	187	SH280:	0

Shoe Type	Quantity	Shoe Type	Quantity	Shoe Type	Quantity	Shoe Type	Quantity	Shoe Type	Quantity	Shoe Type	Quantity	Shoe Type	Quantity
SH281:	341	SH321:	0	SH361:	426	SH401:	0	SH441:	0	SH481:	0	SH521:	249
SH282:	422	SH322:	319	SH362:	433	SH402:	0	SH442:	0	SH482:	128	SH522:	33
SH283:	0	SH323:	0	SH363:	0	SH403:	0	SH443:	0	SH483:	430	SH523:	152
SH284:	460	SH324:	0	SH364:	0	SH404:	0	SH444:	213	SH484:	0	SH524:	92
SH285:	0	SH325:	474	SH365:	304	SH405:	0	SH445:	464	SH485:	0	SH525:	99
SH286:	444	SH326:	5	SH366:	177	SH406:	0	SH446:	0	SH486:	0	SH526:	11
SH287:	416	SH327:	0	SH367:	452	SH407:	449	SH447:	477	SH487:	88	SH527:	305
SH288:	169	SH328:	276	SH368:	0	SH408:	0	SH448:	0	SH488:	0	SH528:	0
SH289:	419	SH329:	403	SH369:	378	SH409:	0	SH449:	184	SH489:	433	SH529:	0
SH290:	104	SH330:	0	SH370:	0	SH410:	232	SH450:	0	SH490:	532	SH530:	0
SH291:	0	SH331:	0	SH371:	0	SH411:	410	SH451:	457	SH491:	179	SH531:	0
SH292:	145	SH332:	0	SH372:	229	SH412:	109	SH452:	0	SH492:	59	SH532:	467
SH293:	0	SH333:	0	SH373:	400	SH413:	0	SH453:	471	SH493:	0	SH533:	0
SH294:	0	SH334:	392	SH374:	0	SH414:	0	SH454:	0	SH494:	61	SH534:	399
SH295:	410	SH335:	0	SH375:	0	SH415:	434	SH455:	0	SH495:	172	SH535:	431
SH296:	0	SH336:	0	SH376:	47	SH416:	0	SH456:	445	SH496:	0	SH536:	16
SH297:	0	SH337:	0	SH377:	143	SH417:	486	SH457:	269	SH497:	440	SH537:	265
SH298:	102	SH338:	40	SH378:	418	SH418:	346	SH458:	153	SH498:	271	SH538:	0
SH299:	421	SH339:	0	SH379:	227	SH419:	308	SH459:	249	SH499:	92	SH539:	0
SH300:	415	SH340:	449	SH380:	0	SH420:	78	SH460:	0	SH500:	420	SH540:	135
SH301:	0	SH341:	430	SH381:	25	SH421:	408	SH461:	0	SH501:	415	SH541:	0
SH302:	0	SH342:	313	SH382:	0	SH422:	0	SH462:	115	SH502:	0	SH542:	0
SH303:	0	SH343:	45	SH383:	0	SH423:	395	SH463:	0	SH503:	0	SH543:	313
SH304:	0	SH344:	0	SH384:	492	SH424:	0	SH464:	407	SH504:	0	SH544:	0
SH305:	0	SH345:	336	SH385:	0	SH425:	461	SH465:	248	SH505:	0	SH545:	0
SH306:	0	SH346:	0	SH386:	0	SH426:	0	SH466:	436	SH506:	0	SH546:	272
SH307:	102	SH347:	175	SH387:	0	SH427:	477	SH467:	178	SH507:	88	SH547:	0
SH308:	270	SH348:	491	SH388:	0	SH428:	0	SH468:	153	SH508:	433	SH548:	0
SH309:	0	SH349:	9	SH389:	0	SH429:	23	SH469:	0	SH509:	0	SH549:	62
SH310:	0	SH350:	0	SH390:	0	SH430:	442	SH470:	388	SH510:	0	SH550:	0
SH311:	0	SH351:	0	SH391:	140	SH431:	0	SH471:	401	SH511:	407	SH551:	0
SH312:	459	SH352:	394	SH392:	0	SH432:	0	SH472:	274	SH512:	14	SH552:	196
SH313:	482	SH353:	0	SH393:	0	SH433:	0	SH473:	267	SH513:	339	SH553:	0
SH314:	397	SH354:	0	SH394:	0	SH434:	0	SH474:	263	SH514:	390	SH554:	0
SH315:	0	SH355:	0	SH395:	379	SH435:	309	SH475:	0	SH515:	0	SH555:	0
SH316:	179	SH356:	180	SH396:	0	SH436:	0	SH476:	447	SH516:	442	SH556:	431
SH317:	379	SH357:	0	SH397:	0	SH437:	0	SH477:	412	SH517:	0	SH557:	471
SH318:	0	SH358:	0	SH398:	0	SH438:	76	SH478:	351	SH518:	0		
SH319:	0	SH359:	13	SH399:	436	SH439:	0	SH479:	494	SH519:	0		
SH320:	446	SH360:	0	SH400:	19	SH440:	0	SH480:	0	SH520:	82		

Appendix D: Complete List of Binding Constraints

Shoe Type		Shoe Type		Shoe Type		Shoe Type		Shoe Type		Shoe Type	
SH002	demand is binding.	SH096	demand is binding.	SH224	demand is binding.	SH312	demand is binding.	SH421	demand is binding.	SH511	demand is binding.
SH011	demand is binding.	SH105	demand is binding.	SH226	demand is binding.	SH313	demand is binding.	SH425	demand is binding.	SH514	demand is binding.
SH013	demand is binding.	SH110	demand is binding.	SH232	demand is binding.	SH314	demand is binding.	SH427	demand is binding.	SH516	demand is binding.
SH025	demand is binding.	SH113	demand is binding.	SH233	demand is binding.	SH320	demand is binding.	SH430	demand is binding.	SH532	demand is binding.
SH027	demand is binding.	SH121	demand is binding.	SH234	demand is binding.	SH325	demand is binding.	SH445	demand is binding.	SH535	demand is binding.
SH032	demand is binding.	SH134	demand is binding.	SH247	demand is binding.	SH329	demand is binding.	SH447	demand is binding.	SH556	demand is binding.
SH034	demand is binding.	SH142	demand is binding.	SH249	demand is binding.	SH334	demand is binding.	SH451	demand is binding.	SH557	demand is binding.
SH038	demand is binding.	SH144	demand is binding.	SH253	demand is binding.	SH341	demand is binding.	SH453	demand is binding.		
SH039	demand is binding.	SH146	demand is binding.	SH254	demand is binding.	SH348	demand is binding.	SH456	demand is binding.		
SH040	demand is binding.	SH150	demand is binding.	SH256	demand is binding.	SH352	demand is binding.	SH466	demand is binding.		
SH044	demand is binding.	SH154	demand is binding.	SH261	demand is binding.	SH361	demand is binding.	SH476	demand is binding.		
SH050	demand is binding.	SH165	demand is binding.	SH262	demand is binding.	SH362	demand is binding.	SH477	demand is binding.		
SH058	demand is binding.	SH176	demand is binding.	SH265	demand is binding.	SH367	demand is binding.	SH479	demand is binding.		
SH062	demand is binding.	SH197	demand is binding.	SH269	demand is binding.	SH369	demand is binding.	SH483	demand is binding.		
SH063	demand is binding.	SH201	demand is binding.	SH277	demand is binding.	SH378	demand is binding.	SH489	demand is binding.		
SH080	demand is binding.	SH203	demand is binding.	SH282	demand is binding.	SH384	demand is binding.	SH490	demand is binding.		
SH087	demand is binding.	SH209	demand is binding.	SH286	demand is binding.	SH399	demand is binding.	SH497	demand is binding.		
SH088	demand is binding.	SH213	demand is binding.	SH287	demand is binding.	SH407	demand is binding.	SH500	demand is binding.		
SH090	demand is binding.	SH221	demand is binding.	SH295	demand is binding.	SH415	demand is binding.	SH501	demand is binding.		
SH095	demand is binding.	SH223	demand is binding.	SH300	demand is binding.	SH417	demand is binding.	SH508	demand is binding.		

Binding Constraints:	
Raw material 1 quantity is binding.	Raw material 119 quantity is binding.
Raw material 5 quantity is binding.	Raw material 120 quantity is binding.
Raw material 9 quantity is binding.	Raw material 121 quantity is binding.
Raw material 13 quantity is binding.	Raw material 122 quantity is binding.
Raw material 16 quantity is binding.	Raw material 124 quantity is binding.
Raw material 18 quantity is binding.	Raw material 125 quantity is binding.
Raw material 19 quantity is binding.	Raw material 127 quantity is binding.
Raw material 22 quantity is binding.	Raw material 128 quantity is binding.
Raw material 27 quantity is binding.	Raw material 129 quantity is binding.
Raw material 31 quantity is binding.	Raw material 132 quantity is binding.
Raw material 32 quantity is binding.	Raw material 133 quantity is binding.
Raw material 33 quantity is binding.	Raw material 134 quantity is binding.
Raw material 35 quantity is binding.	Raw material 137 quantity is binding.
Raw material 36 quantity is binding.	Raw material 139 quantity is binding.
Raw material 40 quantity is binding.	Raw material 140 quantity is binding.
Raw material 43 quantity is binding.	Raw material 142 quantity is binding.
Raw material 48 quantity is binding.	Raw material 143 quantity is binding.
Raw material 56 quantity is binding.	Raw material 145 quantity is binding.
Raw material 57 quantity is binding.	Raw material 146 quantity is binding.
Raw material 60 quantity is binding.	Raw material 147 quantity is binding.
Raw material 62 quantity is binding.	Raw material 148 quantity is binding.
Raw material 68 quantity is binding.	Raw material 149 quantity is binding.
Raw material 79 quantity is binding.	Raw material 150 quantity is binding.
Raw material 81 quantity is binding.	Raw material 151 quantity is binding.
Raw material 82 quantity is binding.	Raw material 153 quantity is binding.
Raw material 84 quantity is binding.	Raw material 155 quantity is binding.
Raw material 85 quantity is binding.	Raw material 157 quantity is binding.
Raw material 86 quantity is binding.	Raw material 158 quantity is binding.
Raw material 89 quantity is binding.	Raw material 163 quantity is binding.
Raw material 96 quantity is binding.	
Raw material 98 quantity is binding.	
Raw material 101 quantity is binding.	
Raw material 103 quantity is binding.	
Raw material 104 quantity is binding.	
Raw material 105 quantity is binding.	
Raw material 113 quantity is binding.	
Raw material 114 quantity is binding.	
Raw material 115 quantity is binding.	

Appendix E: Complete List of Violated Constraints

Demand Violated Constraints		Raw Material Violated Constraints
List of Violated Constraints:		Raw material 1 quantity is violated.
SH002 demand is violated.	SH282 demand is violated.	Raw material 12 quantity is violated.
SH013 demand is violated.	SH295 demand is violated.	Raw material 13 quantity is violated.
SH025 demand is violated.	SH300 demand is violated.	Raw material 24 quantity is violated.
SH032 demand is violated.	SH313 demand is violated.	Raw material 41 quantity is violated.
SH034 demand is violated.	SH329 demand is violated.	Raw material 47 quantity is violated.
SH038 demand is violated.	SH348 demand is violated.	Raw material 51 quantity is violated.
SH058 demand is violated.	SH361 demand is violated.	Raw material 53 quantity is violated.
SH062 demand is violated.	SH362 demand is violated.	Raw material 56 quantity is violated.
SH087 demand is violated.	SH378 demand is violated.	Raw material 64 quantity is violated.
SH088 demand is violated.	SH407 demand is violated.	Raw material 69 quantity is violated.
SH110 demand is violated.	SH421 demand is violated.	Raw material 77 quantity is violated.
SH134 demand is violated.	SH425 demand is violated.	Raw material 80 quantity is violated.
SH146 demand is violated.	SH427 demand is violated.	Raw material 93 quantity is violated.
SH165 demand is violated.	SH451 demand is violated.	Raw material 96 quantity is violated.
SH221 demand is violated.	SH453 demand is violated.	Raw material 101 quantity is violated.
SH226 demand is violated.	SH456 demand is violated.	Raw material 107 quantity is violated.
SH234 demand is violated.	SH466 demand is violated.	Raw material 110 quantity is violated.
SH247 demand is violated.	SH501 demand is violated.	Raw material 113 quantity is violated.
SH254 demand is violated.	SH516 demand is violated.	Raw material 125 quantity is violated.
SH256 demand is violated.		Raw material 126 quantity is violated.
SH277 demand is violated.		Raw material 132 quantity is violated.
		Raw material 138 quantity is violated.
		Raw material 141 quantity is violated.
		Raw material 144 quantity is violated.
		Raw material 148 quantity is violated.
		Raw material 149 quantity is violated.