The Crop Plant Scheduling Problem

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AIRO ODS 2022 Conference, Florence, Italy

September 1$^{st}$, 2022
Introduction

- Determine planting schedules for seed corn, to maximize the weekly production on the given field, while avoiding waste
  - Storage capacity should not be overflowed by the weekly harvest
- The workforce should be cleverly engaged
- Syngenta Crop Challenge in Analytics 2021
- Research funded by Ministry for Higher Education and Scientific Research of AP Vojvodina
Problem Data

- Set of crop populations to be cultivated on the given field
  - Crop population: Planting time window, the needed amount of accumulated GDUs, expected yield amount

- Storage capacity for each plantation

- Historical data about growing degree units (GDUs)
State of the art

– Quite few related works, e.g.:

– Grapes harvest optimization (Albornoz et al., 2021), forest harvest scheduling (Neto et al., 2020)

– However, the problem is gaining popularity, e.g.:
  – AIPLAN4EU Project: Agriculture use case “Campaign-Planning for Silage Maize Harvesting”
Solution Approach

- Forecast expected growing degree units (GDUs) for the planning horizon to be used to determine the harvest week, for each potential planting date.

- Determine optimal harvest schedules to meet the demand and avoid overproduction and waste.

- Backtrack the possible planting dates for each population.

Avoid gaps in harvest weeks and keep their number as low as possible.
GDU / Harvest Forecast

- ARIMA($p$, $d$, $q$) model
  - Parameters determined with the Box-Jenkins method
Harvest Schedule ILP 1/2

- Objectives

\[
\begin{align*}
\min \quad & f_1 = \sum_{w \in W} \left| \sum_{p \in P} h_{pw} Q_p - C \right| \\
\min \quad & f_2 = \sum_{w \in W} u_w \\
\min \quad & f_3 = \sum_{w \in \{1 \ldots |W| - 1\}} \left| u_{w+1} - u_w \right|
\end{align*}
\]
- Objectives

\[
\begin{align*}
\min f_1 &= \sum_{w \in W} \left| \sum_{p \in P} h_{pw} Q_p - C \right| \quad (1) \\
\min f_2 &= \sum_{w \in W} u_w \quad (2) \\
\min f_3 &= \sum_{w \in \{1..|W|-1\}} |u_{w+1} - u_w| \quad (3)
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\min & \quad z = f_1 + c \cdot f_2 + c \cdot f_3
\end{align*}
\]
- Constraints

\begin{align*}
\sum_{w: (p, w) \in F} h_{pw} &= 1 \\
\sum_{w \in W} h_{pw} &= 1 \\
\sum_{p: (p, w) \in F} h_{pw} &\leq u_w \cdot M_1 \\
 h_{pw} &\in \{0, 1\} \\
u_w &\in \{0, 1\}
\end{align*}

\forall p \in P \\
\forall p \in P \\
\forall w \in W \\
\forall p \in P, w \in W \\
\forall w \in W
ILP Results – Site 1

- Instance 1 – 1375 corn populations, planning period of one year, storage capacity 7000 units.

- Solution time$^1$ 28.67 seconds

$^1$ IBM ILOG CPLEX ver. 12.9 on Intel(R) Core(TM) i5-9400 processor at 2.90GHz, with 16GB RAM
ILP Results – Site 2

- Instance 2 – 1194 corn populations, planning period of one year, storage capacity 6000 units.

- Solution time\(^1\) 324.28 seconds

\(^1\) IBM ILOG CPLEX ver. 12.9 on Intel(R) Core(TM) i5-9400 processor at 2.90GHz, with 16GB RAM
Heuristic Solution Approach

- ALNS-based heuristic

- Operators:
  - Rebalancing operators which change the harvest week of some populations from high-quantity harvest weeks to low-quantity harvest weeks
  - Stability operator which aims at equalizing the amount of harvest collected in consecutive weeks
  - Emptying operators which aim at removing all populations from a given week in order to completely avoid harvesting in that week
  - Capacity operator which aims at setting the harvest quantity of a given week as close as possible to capacity
ALNS Results – Site 1

- Instance 1 – 1375 corn populations, planning period of one year, storage capacity 7000 units.
- Approx. 34 min.
- Instance 2 – 1194 corn populations, planning period of one year, storage capacity 6000 units.
- Approx. 31 min.
ALNS Results – Pareto Analysis

The diagram shows a scatter plot with the x-axis labeled "Used weeks" ranging from 28 to 38, and the y-axis labeled "Harvest deviation (f2 and f3 combined)" ranging from 5.70 to 5.74. The points on the plot indicate decreasing harvest deviation over the weeks.
Future / ongoing work

- Enrichment of the problem / model, e.g.:
  - Choice of field and accounting for its capacity
  - Expected yield as a function of the accumulated GDUs amount
  - Robust or stochastic modelling to account for GDU forecast imprecision

- Development of synthetic and real (larger) case studies

- Development of the GA-based algorithm
  - Comparison with the previously developed ALNS heuristic (S metric)

- More detailed forecast of GDUs

\[ GDD = \frac{T_{\text{max}} + T_{\text{min}}}{2} - T_{\text{base}} \]
Conclusions

– We have defined the Crop Plant Scheduling Problem
  – Solvable with the MP solver

– Practical importance and potential
  – Further work on enriching the problem with real aspects
  – Development of solution approach for the enhanced problem version